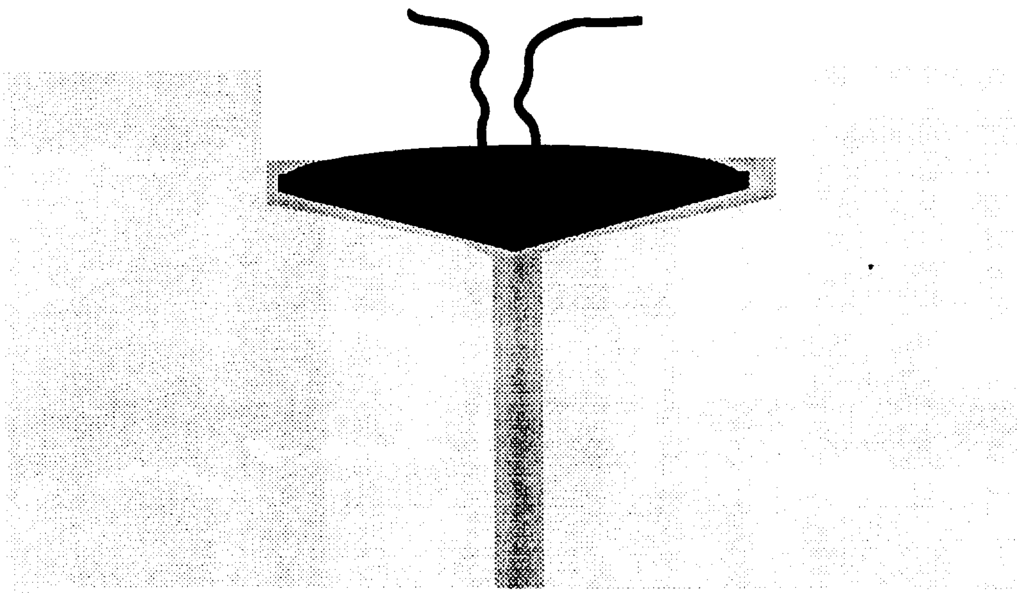
NASA-TM-108001

Antarctic Ice Melter

NASA Ames Research Center
August 15, 1990



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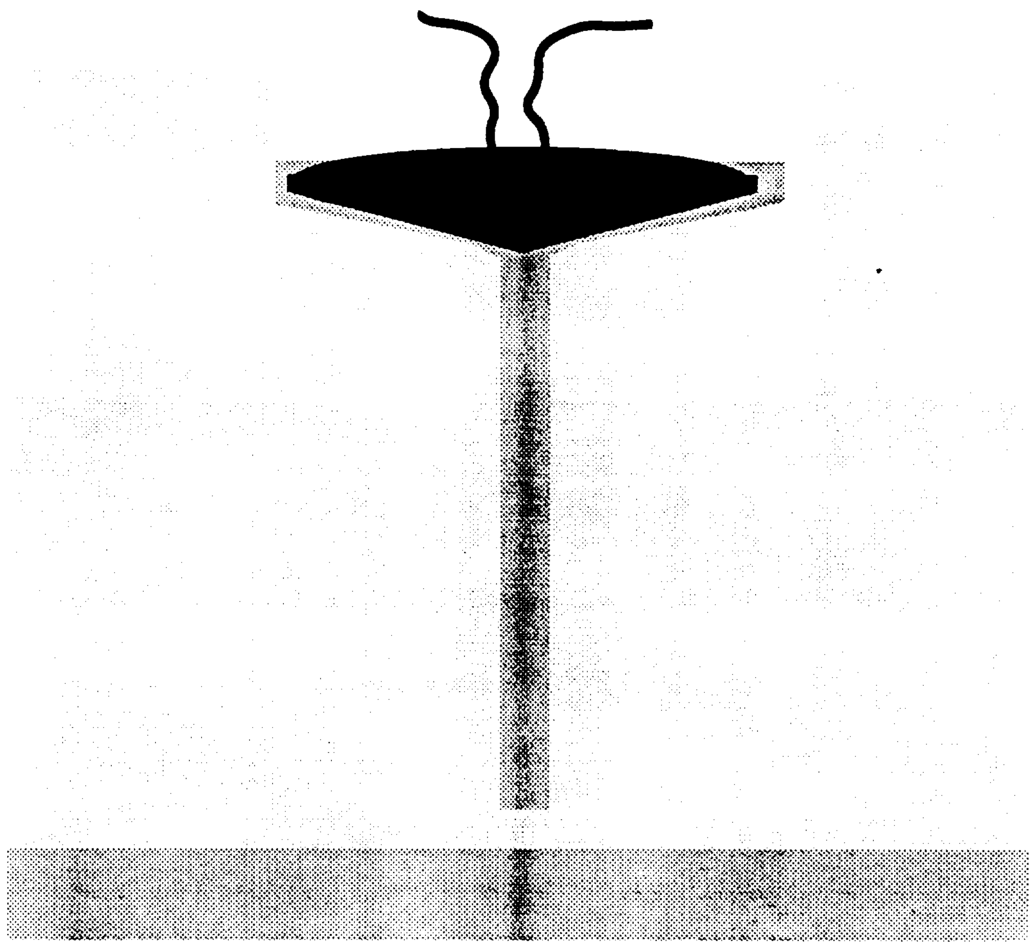

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Abstract

The problem of creating a hole for diver access through in the 4 to 6 meters of ice covering lakes in Antarctica was proposed. After researching possible methods including pressurized steam, heated water jets, and burner systems and comparing energy and time requirements, the burner system was determined to be the most efficient. Assuming a melting efficiency of 50%, this design melts a 1.3 meter diameter hole through 4.2 meter of ice in 15.3 hours and burns 314 pounds of propane.

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Introduction

The purpose of this project is to design a system to allow a diver access to the lakes beneath their frozen surfaces in Antarctica. These scientists are interested in the microbial life found at the bottom of these lakes. They believe that these microbes are similar to the earliest life on Earth and may provide clues towards an understanding of the early evolution of life on this planet and perhaps others.

Design Parameters

To allow access to the water below, it is necessary to create a hole through the ice. This ice can reach depths of up to six meters, though for this project an average ice depth of 4.2 meters is assumed. Also, the hole must be large enough to allow a diver and scuba gear to swim through. A 1.3 meter diameter hole was determined to be an acceptable size.

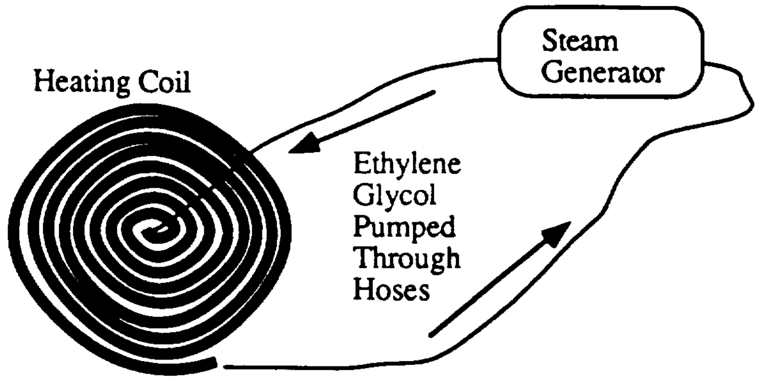
Other parameters are:

1. The system must be environmentally clean. i.e.. Only minimal amounts of chemicals may be added to the environment . (An unavoidable exception is exhaust fumes from burning fuels.)
2. The lowest expected operating temperature is -50 °C(223K)
3. Time to melt should be less that 24 hours
4. Require little intervention by scientists
5. Total system weight should be less than 1600 pounds(790 kg)
6. Must be rather portable and easily maintained
7. The system should last approximately 2-3 years

The Original System

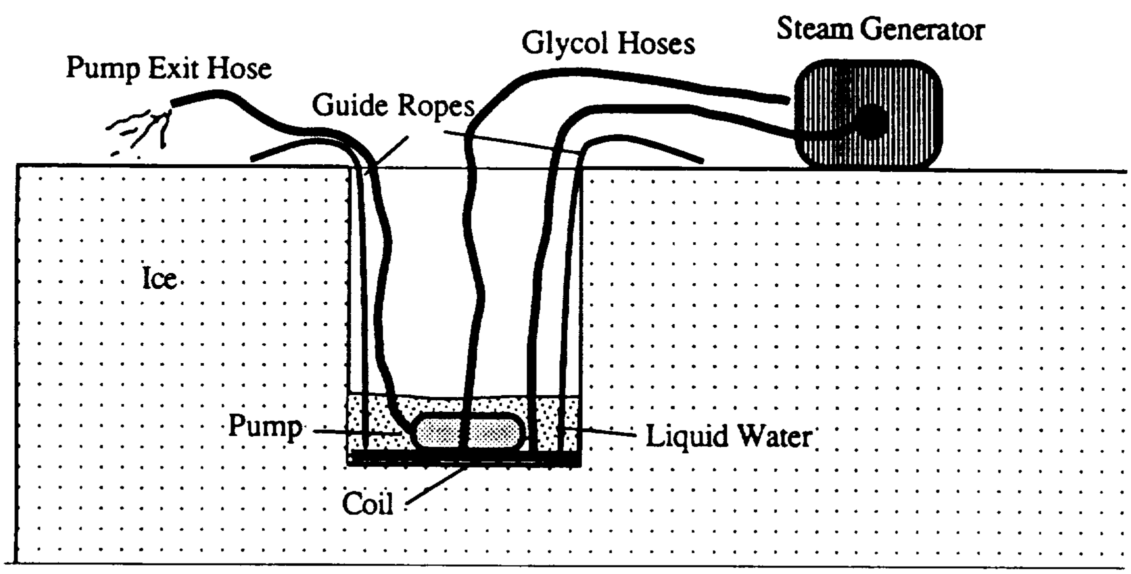
The system now used is rather crude. It was put together from parts that were on hand during the first expedition. A large coil of copper tubing is placed flat on the ice. Ethylene glycol (antifreeze) is passed through a steam cleaner, which heats it, and is pumped through the copper coil. The heated copper coil melts downward through the ice. Glycol was chosen over water as the transport fluid for its lower melting temperature. If water was used and the steam generator quit (which it did, often) the water in the hoses and coil would freeze solid.

As the heated coil melts its way through the ice, a small pump above the coil pushes the liquid water through a hose up and out of the hole. This minimized the amount of heat lost directly to the liquid water.



Original Design Showing Glycol Flow Circuit

The coil and pump are supported by four ropes for directional stability. The present system tends to tilt and melt a narrow slot through the ice rather than a large hole if not watched carefully, even with four guide ropes.



Melter Coil in Hole

Some Problems with The Present System

The known problems with this melter design are:

- It takes too long to melt a hole through the ice. It now takes up to 24 hours to melt one hole through the ice. The new system should create a hole within 12 hours of choosing a site.
- Sand is sometimes trapped in layers within the ice and since the sand is an insulator between the coil and ice it must be removed by hand before melting can continue. The coil must be lifted out of the hole so that someone can climb down hole to remove the sand. The new system should be able to handle sand layers without requiring that the system be removed from the hole.
- It requires constant attention. The steam cleaner quit often, as did the electrical generator. Also, the coil had to be lowered by hand as the ice was melted because it tended to tilt as it melted downwards.
- Some ice fields contain cracks. A hole is created in such an area will always be full of liquid water. It is impossible to pump the water out of the hole. The new system must take into account the possibility of a "wet cut."

Project Overview

The first step in this project was to define the problem as clearly as possible. A list of requirements, or needs, for the system this system was developed. Then some specifications were attached to these needs. An example of this is:

Need: Create a hole through the ice.
Specification(s): 1. Maximum ice thickness is 6 meters
2. Desired hole diameter is 2 meters

Once the problem had been defined, the initial research could be more easily carried out. This research was primarily to provide the researches with background information on conditions in the antarctic and the various methods now in use for creating holes in ice. After this research, a list of possible methods for creating a hole in the ice sheet was compiled. The general methods found were:

- Heat - Direct (Burners)
- Heat - External Fluid Flow (Water Jets)
- Heat - External Fluid Flow (Steam Jets)
- Heat - Internal Fluid Flow (Coils)
- Heat - Electrical Resistance
- Mechanical - Drills, Augers
- Chemicals
- Explosives

Next, the advantages and disadvantages of each general category were listed and compared. This allowed the removal of some methods which were either impractical for this application or undesirable to use.

Further research into the remaining methods followed, including contact with companies who make equipment which might have been applicable to this problem. This research, including some preliminary calculations, removed all but one system from the list: Direct heating of the ice.

Discussion of the Various Systems Considered

Many other ways of creating a hole in the ice were considered besides the coil, water and burner methods. Below are descriptions of each method and the reasons why each are inapplicable to this problem.

Explosives

Explosives have the potential to create a large enough hole in a very short time, while also being very small and light. On the other hand, they could also damage the balance of nature that the scientists are trying to study. This removed explosives from the list immediately.

Chemicals

The use of chemicals was also another good idea. Certain solutions when mixed together create large amounts of heat. A simple example is a hand held heat pad that snow skiers use. This concept was rejected because of the possibilities of contamination or pollution represented by the large quantities of chemical required.

Mechanical

The most obvious way to create a hole is to dig one. This is not a bad idea, but the largest hole that can be made at the present using a one or two man auger is about 9 inches. To make one any larger a system has to be flown in. The reason for this is that there is a great amount of torque and something with a great deal af mass has to be used to withstand this torque. In this case, something mounted on a truck could do the job and that is precisely the problem.

Electrical Resistance

Another good idea was to use electricity. A metal cylinder or metal something with a high conductivity with a high amount of voltage running through it could be used. The problem with this idea is that to feed this amount of energy to a system would require something the size of a power plant.

Internal Fluid Flow - Coils

This was the original method used to create a hole in the ice. While it is probable that the efficiency of this system could be improved dramatically, it was decided that other methods offered even higher melting rates and efficiencies.

External Fluid Flow - Steam Jets

Steam would also be a great way to melt the ice for it has large amount of energy. The design for a system using this energy source would not be complicated to make, however the same problem becomes apparent. In order to make this system work a boiler needs to be used to vaporize the water and a boiler to put out a high enough flow rate also is not portable. The calculations made by John Muhlner for the hot water system led to the same result. A flow rate of 15 gallons a minute was needed to allow for the system to be effective and the portable hot water heaters only put out 3 to 5 gallons a minute of hot water.

External Flow - Hot Water Jets

Currently, hot water drilling is being used in the Antarctica and is capable of penetrating a 20 cm width by 50-200 m deep hole. This method is used to retrieve core samples from the ice. The idea here is to use the same existing technology, i.e.; equipment, and to design an orifice that would allow for the required diameter hole. A hot water drill system consists of a water heater, water pump, hoses to feed and recover water from the system. All of this equipment is commercially available and the amount of time required to assemble the system is kept to a minimum.

Propane Infrared Burner Design

The most effective way to melt ice is to create the heat at the location it is needed. Originally, this concept was to line the inside of a cavity with bare flames, similar to what is found in a gas kitchen stove. This design later evolved into using infrared burners strategically placed on the inside of the cavity facing downward. This is the concept presently being used in the design of the ice melter.

As was stated before, the original system is very slow and inefficient. Using the burner system, the propane fuel is burned at the heating location and converted into the energy to melt the ice. This effectively skips the intermediate steps in the original system.

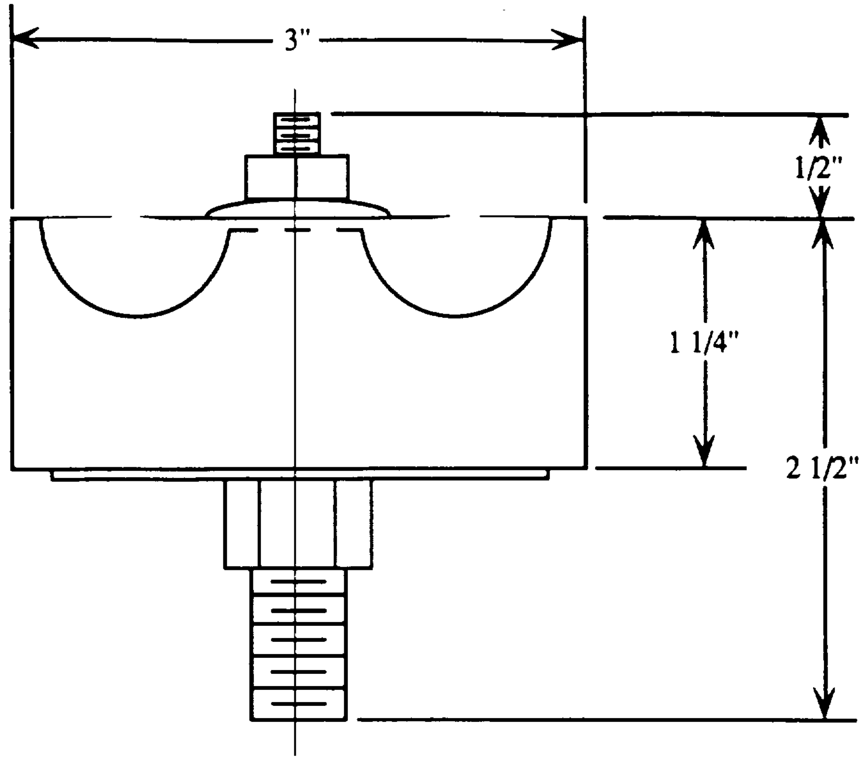
The burner system also reduces the total number of devices required. The original system includes the following pieces of equipment: copper coils, a steam cleaner, generators, steam hoses, garden hoses, pumps, two barrels of fuel, fluid for the system, and a hurdy gurdy. The burner system, on the other hand, requires the following: the enclosed cavity, a pump, lead weights, rubber tubing, two blowers, a generator, and propane bottles. This procedure not only uses fewer devices but also lessens the amount of time spent in preparation as well as time monitoring its use.

The fuel to be used is propane. Propane was chosen for its ready accessibility and relatively high heat content. Propane has a rating of 2572 BTU/hr-ft^3 and is one of the most widely used fuels. However, propane does liquify at -42°C. This should not present a problem, though. If the bottles are painted a dark color they will absorb a substantial amount of energy from the sun, thus keeping the internal temperature well above propane's freezing point. This has been tested by researchers at Lockheed and is the process they use during the summer months in Antarctica to keep propane in a gaseous state. If for any reason there are problems then the propane will have to be pressurized using nitrogen. This is also a common practice by Lockheed researchers in the Antarctica during the winter months when the temperatures are around -75 degrees C. More Information on this process is accessible by contacting Jack Doolittle at Lockheed in Palo Alto, California.

The propane sits on the surface in 80lbs bottles that hold 100lbs of propane each, thus the total weight of a single full bottle is 180lbs. The possibility of using larger bottles that hold more gas remains, however because these bottles are to be moved from place to place it might be favorable to carry the smaller ones. Depending on a few specifications as well as the efficiency of the system the amount of propane varies between 3 to 4 bottles.

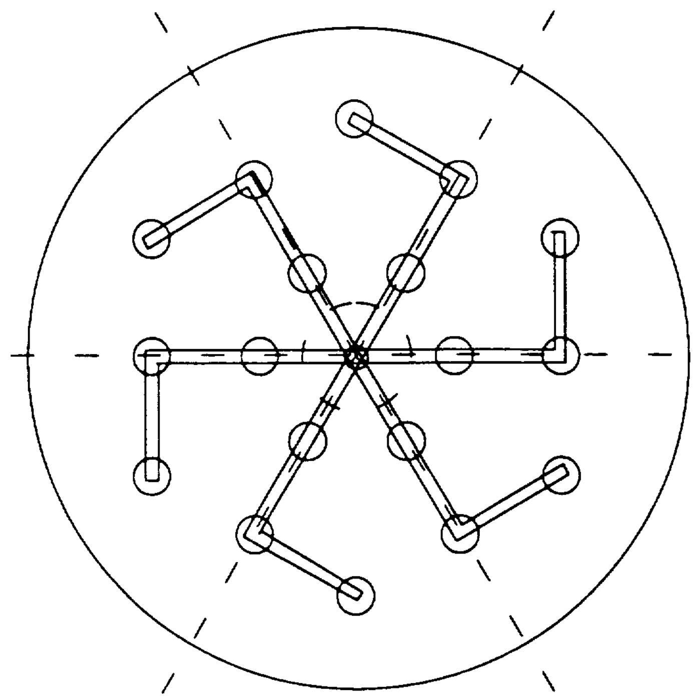
The use of propane makes the entire operation a simple process. The propane is taken directly from the bottle with the pressure controlled by a regulator. It is then mixed with air in a ratio of 1 to 10. The air is supplied by a blower which also sits on the surface. The two fuel and air are mixed at a T (See appendix) and the mixture is pumped to the burners in the enclosed cavity.

These burners are manufactured by Burdett Manufacturing Company in Illinois. The number 21 cup burners were chosen because of their size and performance. The infrared burners are efficient in both heat transfer and fuel consumption. They produce radiant and convective heat which are absorbed by the lower wall of the enclosed cavity. The burners heat up the cavity to a certain temperature and continue to radiate heat to the surface at a constant rate. The amount of heat produced depends on the pressure of the gas mixture (fuel flow rate) as well as the opening of each burner, both of which can be adjusted to increase efficiency.



Number 21 Burdett Cup Burner

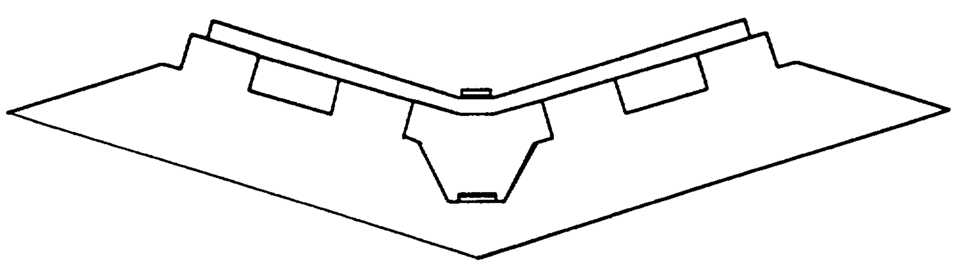
The cavity encloses 18 of these infrared burners which are spaced evenly over the majority of its surface area . A graph in showing the specs on the burners due to the different opening sizes and pressures appears in the appendix. Each burner is three inches in diameter and about 3 inches in height and is housed in a raised compartment which minimizes the total volume of the cavity. The compartments could be connected by ignition tubes which could carry the flame from one burner to another, which would make the lighting process much easier. These can be added if desired. Behind all of this are the burner manifolds which are the tubes that take the propane and air mixture to the burners. These tubes are one inch by one inch and are welded to the back of the cavity. Holes will be drilled and threaded and the burners will then be screwed directly into them. These manifolds, igniter tubes, and burners as well as the compartments that hold the later two are what make up the majority of the top plate of the cavity. The arrangement of the burners and manifold system is shown on the following page. This piece will be detachable for easy maintenance and ignition of the burners, therefore a water-tight seal must be placed between the upper and lower halves of the cavity. The top half should also be insulated to reduce the amount of heat escaping upward.



Each circle represents a burner

Projected View of Burner and Manifold Layout

The lower section of the cavity is a modified cone as shown below. The cone shape will give some directional stability to the system as it melts through the ice. It will also allow sand to flow down into the 9 inch jiffy drilled hole. This cone will be made out of 1/4 inch stainless steel because it is durable, can withstand intense heat, and has a high absorptivity of infrared radiation (89% at 1000 degrees F). The total enclosed volume is minimized to reduce the buoyancy of the system. The design at present weighs 303 lbs. The buoyancy of the melter, which is determined by the mass of water that is displaced by the melter is 287 lbs. This is because the total enclosed volume of 0.13 m^3. The reason for this is that the burners have to be mounted from 4 to 6 inches away form the surface it is heating. This design has the burners 5 inches away which makes a total volume of the modified cone .275 m^3.



Side View of Melter

In order to keep the whole process a dry cut a pump will have to be used to lift out all the melted ice. A submersible pump that works at cold temperatures as low as -50 degrees F at a rate of up to 19 gallons a minute can be purchased from Bruce Barton Pump Service in San Jose. It will be mounted on the top plate and will pump the water as it flows into its concavity. A smaller one could probably be used, however this should be considered after testing of the prototype as the required pump rate has not been determined.

The electricity to power this pump as well as two air blowers will come from some sort of generator. This could be the one already in use there or one that uses propane. Teledyne Energy Systems in Timonium, Maryland makes a thermal generator that runs on propane. However, they are expensive and may not be efficient enough for three systems to run on. This particular generator should be researched further.

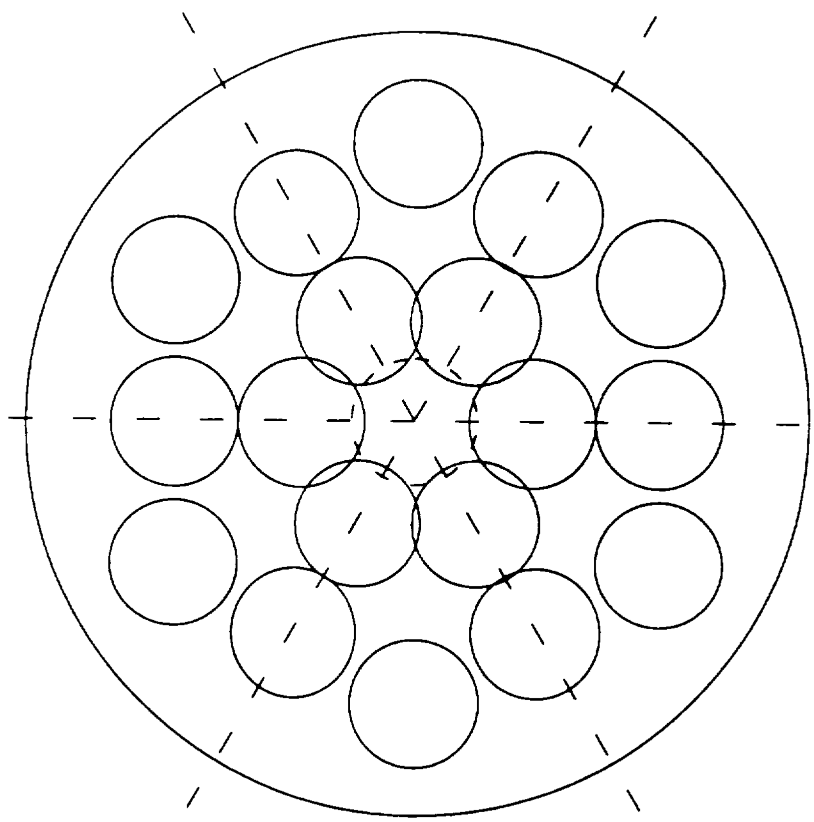
One of the air blowers previously mentioned will be used to keep fresh air circulating through the cavity. The reasons for this are to keep the internal temperature steady, allow the burners to burn at an efficient rate, and help transport the products of combustion, carbon dioxide and water, out of the cavity. The air, water, carbon dioxide, and excess heat will be exhausted through a number of one way gas valves on the upper surface of the cavity .

Maintenance of this system should not be a problem since the burners are made to operate at temperatures of 1000 degrees F. The refractories of the cups, however, are made out of a ceramic material and may be prone to cracking or chipping. One way of minimizing this problem is to transport the refractory cups separately from the melter. If a refractory cup does break, a replacement is cheap as well as easy to install. It can be replaced by unscrewing the burner and swapping the broken piece for a new one.

Heat Transfer To The Surface Of The Cone

The amount of heat that is transferred to the surface of the cone depends on the number of burners, the type of burner, the rate at which they are burning, the temperature and pressure at which they are burning, and the type of surface material.

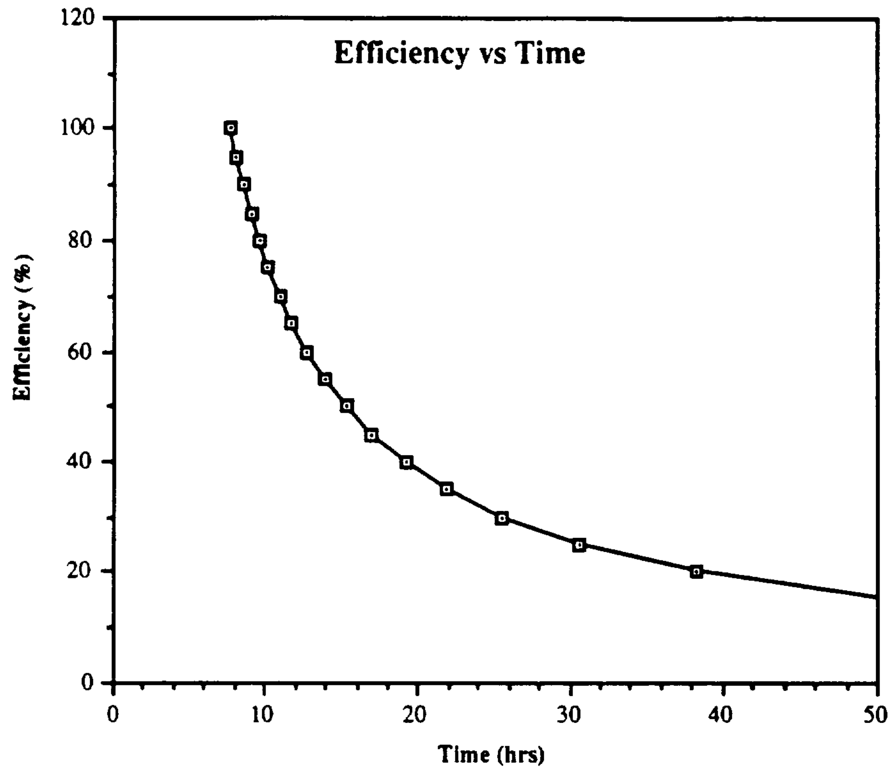
For this design the #21 cup burner was chosen because it is relatively small and radiates heat in a radially symmetric pattern. 18 of these burners cover most of the lower surface area of the cavity (See Below). The fuel pressure will be adjusted to 6 inches of water column which allows 25,000 BTU per hour to be released by each burner. 40% of this energy is radiant heat and of that 89% of it is absorbed by the stainless steel surface. The rest of the heat comes from the convection due to the air that is circulating through the cavity. Maintaining the temperature at 1000 degrees F by means of blowing 142 ft^3/min of air results in 8,100 BTU/hour/ft^3 transferred to the surface. These calculations are shown in the appendix.



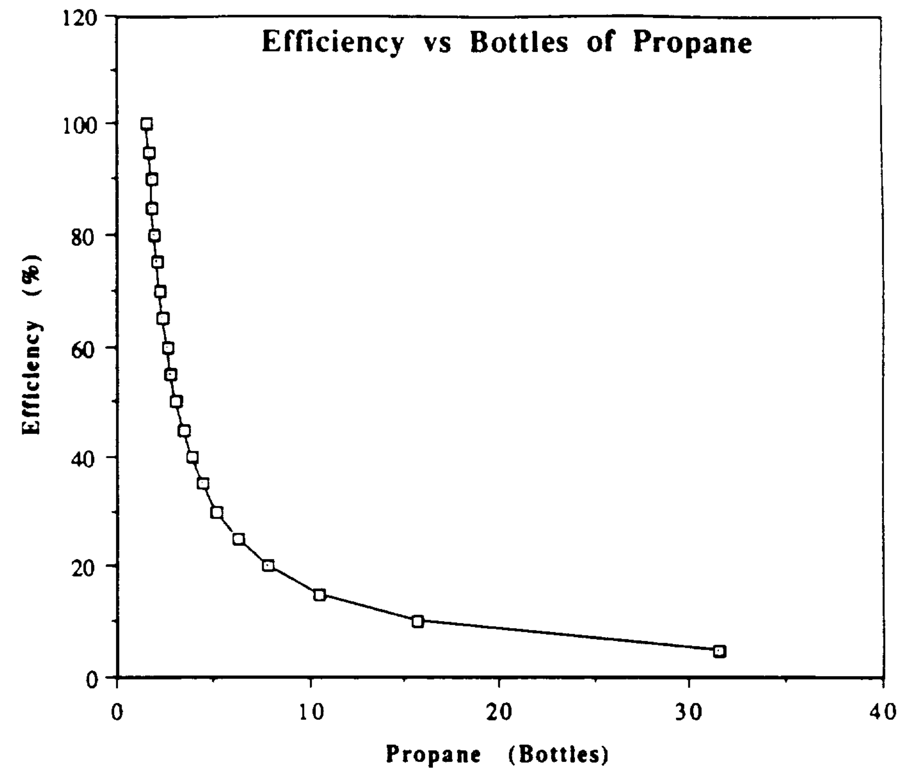
Burner Radiant Heat Distribution

Knowing the amount of heat transferred to the surface and the total amount of energy needed to melt the ice, the amount of time the whole process takes can be calculated. An assumption for the efficiency of the heat transfer to the ice had to be made at this point. It was assumed that 50% of the heat going through the surface of the cavity would go into melting the ice. This is a very difficult system to model as there are two phase changes (to liquid and to steam) as well as flows related to those two phase changes. A numerical model for lower temperatures (i.e. non-boiling) was derived for this system. The results of this model show that a 50% efficiency may be too high. Actual testing of this system is suggested. Graphs of the efficiency versus the time and amount of propane needed can found below.

Using a 50% efficiency, the system melts the ice in 15.3 hrs and uses 314 lbs of propane.



Graph of Efficiency vs Time



Graph of Efficiency vs Propane Bottles Required

Set-up and Use of the ice melter

After unloading the helicopter and dragging all the equipment to the appropriate spot, the system can than be prepared for use. First, a jiffy drill hole should be made at the desired location to within a few feet of the bottom of the ice. Then the top part of the cavity is opened and the 18 burners are screwed into the open compartments. The burners are much more likely to be broken if they are transported in the enclosed cavity. A hose attaches the propane bottle to the mixing system which includes the regulator, gas cock, and mixing T. One air blower is connected to the mixing T and the other exhaust system of the cavity. Now, after gas and blowers are turned on the burners are ignited, probably by a long-handled lighter. Then the top part of the cavity is securely closed. The melter is put into position over the jiffy drill hole and left to begin melting. All that is left to do is wait for the ice to melt and periodically check to see if all systems are going alright.

Conclusions and Recommendation

In order to melt ice many possible designs could be made, however for this system to be portable, durable, lightweight, and fast working, as it needs to be for use in Antarctica , not many of these will work. It is therefore recommended that the burner system be used because a much greater efficiency can be attained by directing the heat straight to the ice surface and not through any intermediate steps. This system assuming 50% efficiency will melt all the ice in 15.3 hours and consume 3.14 bottles of propane. The melter itself weighs 303 pounds and the entire system 1433 pounds. If continued research and testing is completed then new designs of this system could be made. By doing so there are greater possibilities of lowering the amount of weight, time and fuel needed to melt the hole into the ice.

Future Work

Due to lack of time, there are still a few points that need to be looked into for the burner system whether they are for this design or for one in the future. Some of these ideas are for this design but others possibly could make this system more effective by increasing its efficiency. These ideas include the water proof seal, insulation, gas valves, lead weights, pump, fins, compressor/generator system, corrosion of materials, and line burners.

The seal the top plate makes with the surface area of the cone needs to be considered because of its importance. The seal itself needs to be waterproof, the material that might be best would be some kind of o-ring. Something this size should not be to much of a problem.

The top plate of the cavity should also be insulated. The reason for this would be to keep the temperatures from getting too hot on its surface, so it can be touched when lifting it out of the hole. Fiberglass is one idea but further research needs to be done to find the best material.

In order to not have exhaust the air all the way at the surface, the use of ~~line~~ one way gas valves could be used. Two reasons why this should be done are one, no material besides metal can withstand this kind of heat so a flexible tubing is out of the question and two, it might be possible to direct all the heat coming out in exhaust into the center of the hole. To do this one way gas valves could be used, but this needs to be looked into further.

Lead weights will be used to used to make the entire system heavy enough so that it will not float. Trays to lay these weights on might be the best approach or possibly just putting shot into bags might due the trick. This part of the design remains to be done.

As it stands now a pump is being used to lift out all the water in a dry cut. This, however might not be necessary for the amount of heat that reaches the surface touching the ice remains the same. The exhaust form the system possibly could keep the water warm and help also in melting the ice.

A future design possibility could also include fins on the surface area of the cone that touches the ice. It would use the same concept that an amplifier uses to cool itself down. By using fins the surface area could be made increased significantly and that would result in a larger amount of heat transferred to the ice.

Instead of just using separate generator and blower systems, why not combine the two or three and use a compressor/generator. A system of the sort could be purchased that would take care of all these applications and this would cut down on the number of devices used as well as the weight.

One thing that needs to be checked is the corrosion properties of the metal used in the design. How long and how durable is it at 1000 degrees F? The manufacturers at Burdett assured that this would not be a problem but it should to confirmed. In case that it is a problem the temperature could be lowered but this would in turn lower the efficiency of the system.

The last suggestion for future designs is the possibility of using line burners. The reason for this is that they radiate 15 to 20% more radiant heat than the cup burners. The problem with using them in this design is that they take up too much space. It would be difficult to arrange them in a way to cover a large amount of the surface area and further more the volume would increase resulting in a greater amount of weight needed to keep the system from floating.

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Appendices

Appendix A

Notes on the "Ice Hole" project:

1. The power source is in general any two 5kw generators we can get that work. Usually this has been a battery start Niagra 5 made by Generac. It is 5kw, 120 and/or 240 volts, single phase, and is run by an 11 hp (@3600 rpm) Briggs and Stratten engine.

2. The weight of the current system is about the following:

Steam cleaner (with skids for ice)	= ~400lbs
copper coil	= ~100lbs
generators	= ~125lbs (x2)
steam hoses (50ft)	= ~ 60lbs
garden hose	= ~ 15lbs
sump pumps (2-3)	= ~ 5lbs each
1 barrel kerosene	= ~ 400lbs (1 per hole melted)
1 barrel gasoline	= ~ 400lbs (.75/hole)
Glycol	= ~ 200lbs (20 gals)
plywood (4 sheets 4x8)	= ~ 150lbs
tools (plumbing)	= ~ 100lbs
hurdy gurdy (for pumping fuel)	= ~ 100lbs

3. The copper tubing is standard plumbing stuff ? ~3/4" I think - I don't remember the inside diameter. Whatever we could find at the time.

4. The hose used to transport the glycol soln. was steam rated hose - I don't remember the specifics but it is pretty tough stuff and very heavy duty.

5. Set up =

A. Move all the equipment to melting site (like in film)
B. Hook up hoses to the coil and steam cleaner
C. Fuel generators, steam cleaner
D. Prime steam cleaner with glycol
E. Pump glycol soln through the system
F. Ignite steam cleaner
G. Watch ice melt, baby-sit equipment, watch coil (the coil needs to be watched closely to keep it from "wandering" in order to make a straight hole - this is accomplished by tying the coil off to ice screws set into the ice and periodically loosening the rope)

A

2.54 cm/in m/100 cm in/ft

.3048 m/ft

3.28 ft/m

Present Situation

Diameter of Hole = 4 → 4.5 ft
Height = 2.8 → 5.5 m
Time = 6 → 9 inch/hr 18 - 24 hr

Assume: Diameter : 4.25 ft ≈ 1.3 m
Height : 4.25 m
Time : 21 hrs

Volume ⟹ 5.64 m^3 ice
Total Energy needed ⟹ 2,160,000 BTU

Using Steam generator (like landas) PSC3-3000
GPM = 2.5 / 300 °F
BTU/hr = 380,000
Fuel consumption 2.75 gal/hr

$$\frac{2,160,000 \text{ BTU}}{380,000 \text{ BTU/hr}} = 5.68 \text{ hrs}$$

$$\frac{5.68 \text{ hrs}}{21 \text{ hrs}} = 27\% \text{ efficiency}$$

Fuel 2.75 gal/hr (21 hrs) = 57.75 gal of fuel

A

Design Parameters

We have come up with several parameters based on the information we have been given and the calculations and conclusions we have made. These parameters are as follows:

1) Weight- <= 1600 lbs
2) Space- as small as possible
3) Hole- 2 m diameter
   6 m deep
4) Time- <= 12 hrs
5) Melter- submersible
6) Energy- 6.8×10^9
7) Energy source- something to create this amount of energy!!!
8) Fuel- enough to feed this energy source!!!
9) Tubing- high conductivity (on melter)
   low conductivity (to melter)
10) Pump- submersible
    rate = 19.2 gallons/min (4 hrs)
11) Fluid- low conductivity
    non-freezable
12) Tripod-
13) Control mechanism-

1) # of components - minimal
2) reliability of equipment (fix in field)
3) faster

A

Needs and Specifications

Minimize weight- $\leq$ 1600 lbs

Minimize volume- as small as possible

Create hole through ice - 2 m diameter

6 m deep

Minimize Melting Time- $\leq$ 12 hrs

Withstand the environment - submersible

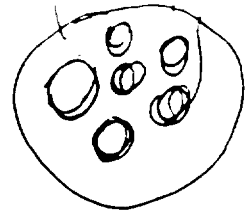
Minimize total energy required (i.e. maximize efficiency) - 6.8×10^9

Provide enough energy to melt ice- something to create this amount of energy!!!

Minimize fuel requirements - enough to feed this energy source!!!

Remove melted ice - submersible pump with rate of 19.2 gal/min.

Appendix B



Design:

- Spiraling copper tubing
- Insulating material on inside of dish
- Supporting structure of steel
- Pump secured ~~on~~ inside the dish
- Etheyle Glycol pumped down to center then spirals
- Heavily insulated rubber tubbing
  carries glycol down & back up to heater

- Fuel for Heater
  probably methane or propane
- Heater - to heat up glycerol
- Generator - electricity to pump & heater if needed
- Tripod - to control hoses

B

Calculations

Assume : mass rate flow = 20 gallons/min

$20\ g/_{min}\ \frac{min}{60\,sec} = .3333\ gal/_{sec}\ \frac{m^3}{264.2\,gal} = 1.262 \cdot$

Cross sectional Area = πr^2

$r = \frac{1}{2}\,in = .5\,in\ \frac{2.54\,cm}{in} \times \frac{m}{100\,cm} = .0127$

$A\ \pi r^2 = 5.067 \times 10^{-4}$

$V = \frac{1.262 \times 10^{-3}\ m^3/_{sec}}{5.067 \times 10^{-4}\ m^2} = \boxed{2.49\ m/s}$

Assume : 10 gallons/min

$10\,gal/_{min}\ min/_{60\,s}\ \frac{m^3}{264.2\,gal} = \cancel{3.755 \times 10^{-3}\ m^3/_{sec}}$ $6.3084 \times 10^{-4}\ m^3/_{sec}$

$A = \pi r^2 = 5.067 \times 10^{-4}$

$V = \frac{\cancel{3.755 \times 10^{-3}\ m^3/_{sec}}\ 6.3084 \times 10^{-4}\ m^3/_{sec}}{5.0671 \times 10^{-4}\ m^2} = \cancel{7.42}\ m/s\ \boxed{1.245\ m/s}$

$\approx 1/3\ hp.$

B

	A	B	C	D	E	F	G	H
1				Ice Melter- Steam				
2								
3	28-Jun-90							
4								
5	Specs from Karcher							
6	(800) 643-3366							
7	Steam Cleaner called ?							
8								
9	Imputs:							
10		Temperature	151.67	C	s ~ steam			
11		Pressure	600.0	psi	c ~ cavity			
12		Output rate	1.80	gall/min				
13		Tubing	0.375	in I.D.				
14		Weight	350.0	lbs				
15		Nozzle Dia	0.32	in				
16			0.008128	m				
17		# Holes	250.00					
18		Hole Dia	0.0005	m				
19								
20	Calculations:							
21		Mass rate flow of steam				Ms=	0.0001136	m^3/s
22			264.2 gall = 1 m^3					
23			Ms=	Rate *(min/60s)*(m^3/264.2 gall)				
24								
25		Mass flow has to be the same on both sides						
26			Ms = Mc					
27			M = V*A					
28			Vs*As = Vc*Ac					
29								
30		Area of the nozzle				As=	0.0000519	m^2
31			As=	πR^2				
32								
33		Velocity of the steam				Vs=	2.1884243	m/s
34			Vs=	Ms/As				
35								
36		Area of the holes in the cavity				Ac=	0.0001963	m^2
37			Ac=	πR^2*(#Holes)				
38								
39		Velocity of steam leaving the cavity				Vc=	0.5783076	m/s
40			Vc=	Vs*As/Ac				

B

Heat des [illegible]

$$\dot{Q} \approx \dot{m}(h_2 - h_1)$$

T_1 131°C P_1 = 4.137 MPa

$h_1 \approx 570$ kJ/kg

T_2 = 137°C P_2 = .1135 MPa

h_2 = ~~[illegible]~~ 2755 kJ/kg

$\dot{m}$ = 1.1355×10^{-4} m³/s

1.1355×10^{-4} m³/s (1000 kg/m³) = .1135 kg/s

$\dot{Q}$ = .1136 kg/s (2755 − 570) kJ/kg

$\boxed{248 \text{ kJ/s}}$

226 kJ/s (3600 s/hr) = 8.94×10^5 kJ/hr

7.6 [illegible]

1A B

Velocity of steam

$1.8\ \text{gal}/\text{min} \left(\text{min}/60\ \text{s}\right)\left(\text{m}^3/264.2\ \text{gal}\right) = 1.1355\times10^{-4}\ \text{m}^3/\text{s}$

$1.1355\times10^{-4}\ \text{m}^3/\text{s}\ \left(\overset{\rho}{1000}\ \text{kg}/\text{m}^3\right) = .1136\ \text{kg}/\text{s}$

$D = 3/8\ \text{in} \left(\frac{2.54\ \text{cm}}{\text{in}}\right)\left(\text{m}/100\ \text{cm}\right) = .009525\ \text{m}$

$$A_1 = \pi r^2 = \pi \frac{D^2}{4} = 7.1256\times10^{-5}\ \text{m}^2$$

$$\dot{m} = VA \quad \therefore \quad V = \dot{m}/A$$

$$V = \frac{1.1355\times10^{-4}\ \text{m}^3/\text{s}}{7.1256\times10^{-5}\ \text{m}^2} = \boxed{1.594\ \text{m}/\text{s}}$$

Mass flow the same on both sides (inlet & exit)

$\therefore \quad V_1A_1 = V_2A_2 \qquad \dot{m} = \dot{m}$

Assume: $D_2 = 1\ \text{mm} = .001\ \text{m}$

250 holes

$$A_2 = \pi \frac{D^2}{4} = 7.854\times10^{-7}\ (250\ \text{holes})$$

$$1.9635\times10^{-4}\ \text{m}^2$$

$$V_2 = \frac{V_1A_1}{A_2} = \frac{1.1355\times10^{-4}\ \text{m}^3/\text{s}}{1.9635\times10^{-4}\ \text{m}^2}$$

$$= .578\ \text{m}/\text{s}$$

ORIGINAL PAGE IS
OF POOR QUALITY

$\left(1_{13}\right)$ B

After exit

Density: steam [illegible] than H_2O

999.8 kg/m^3 [illegible] at 6°C

[illegible] at [illegible] °C

930.5 kg/m^3 at 135 °C

$\therefore$

.0010002 m^3/kg at 6 °C

.0010747 m^3/kg at 135 °C

steam is $\underline{1.074}$ × Volume

$$1.1335 \times 10^{-4}\ m^3/s\ (999.8\ kg/m^3) = (930.5\ kg/m^3)\ X$$

$$X = \dot{m}_2 = 1.218 \times 10^{-4}\ m^3/s$$

Therefore $$V_2 = \frac{\dot{m}_2}{A_2} = \frac{1.218 \times 10^{-4}\ m^3/s}{1.9635 \times 10^{-4}\ m^2} = .62\ m/s$$

B

1c

Head loss

$$\dot{Q} = \dot{m}(u_2 - u_1) + \dot{m}\left(\frac{P_2}{\rho} - \frac{P_1}{\rho}\right) + \dot{m}g(z_2 - z_1)$$
$$+ \int_{A_2} \frac{V_2^2}{2}\rho V_2 \, dA - \int_{A_1} \frac{V_1^2}{2}\rho V_1 \, dA_1$$

when T = ... 600 ... .137 MPa
u_1 = 567.35

Downstream perform ...

$T = 137°C$ P 1.135×10^5 Pa .1135 MPa
$u_2 \approx 2560$

$$P_2 = P_1 + \rho\left(\frac{V_1^2}{2} - \frac{V_2^2}{2}\right)$$
$$= 4.135\,\text{MPa} + 1000\,\text{kg/m}^3\left(\frac{(1.5961)^2}{2} - \frac{(.578)^2}{2}\right)\ (1.02\ \text{m}^2/\text{s}^2)$$

$P_2 =$ 4.135 MPa

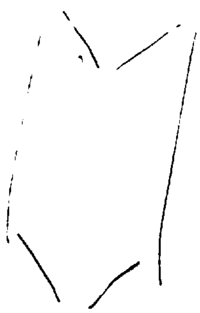
$\dot{Q}$ ~ minimal

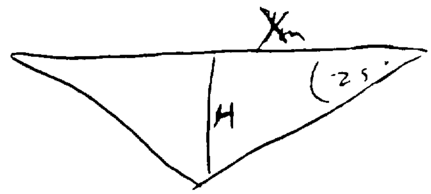
B

	A	B	C	D	E	F	G	H
1	Ice Melter- Water							
2								
3	28-Jun-90							
4								
5	Specs from NSTC Farmtec				s ~H2O			
6	Dick				c ~ cavity			
7	(415) 483-7394							
8								
9	**Imputs:**							
10		**Heater:**			**Cavity:**			
11		Temperature	85.00	C	Diameter		2.00	m
12		Pressure	2100.0	psi	Circumfrance		6.28	m
13			1.44E+07	N/m^2				
14		Output rate	4.50	gall/min	# Holes		80.00	
15		Tubing	0.375	in I.D.	Hole Dia		0.033	in
16		Weight	450.0	lbs			0.0008382	m
17		Nozzle Dia	0.065	in				
18			0.001651	m				
19		Fuel rate	9.00	q/hr				
20			2.25	gall/hr				
21		Time	19.00	hrs				
22								
23	**Calculations:**							
24		Volume rate flow of water				Mw=	0.0002839	m^3/s
25			264.2 gall = 1 m^3					
26			Mw=	Rate *(min/60s)*(m^3/264.2 gall)				
27								
28		Volume flow has to be the same on both sides						
29			Mw = Mc					
30			M = V*A					
31			Vw*Aw = Vc*Ac					
32								
33		Area of the nozzle				Aw=	2.141E-06	m^2
34			Aw=	πR^2				
35								
36		Velocity of the water				Vw=	132.6003862	m/s
37			Vw=	Ms/As				
38								
39		Area of each hole						
40			A =	πR^2		A =	5.5180E-07	
41								
42		Area of the holes in the cavity				Ac=	4.414E-05	m^2
43			Ac=	πR^2*(#Holes)				
44								
45		Velocity of steam leaving the cavity				Vc=	6.4306317	m/s
46			Vc=	Vw*Aw/Ac				
47								
48		Burnulli's (sp?) Equation for pressure				Pc=	14488270.75	N/m^2
49			Pw + Vw^2/2 = Pc + Vc^2/2				2101.27	psi
50								
51								
52		Fuel Needed				F =	42.75	Gallons
53			Fuel = Rate * Time					

B
Rube / pielt

Hot H_2O





$\tan 25 = \frac{H}{1\,m}$

$h = .46\,m$ $\qquad x = .9865\,m$

$2x = 1.973\,m$

Surface Area $= \pi r \sqrt{r^2 + h^2}$

$= 3.373\ m^2$

Volume of Ice $= 18.85\ m^3$

Energy to Melt $= 7{,}211{,}000$ BTU

Thickness $= \frac{18.85\ m^3}{3.373\ m^2} = 5.59\,m$

\# of Hours to melt = 10

$10\,hr \cdot \frac{60\,min}{1\,hr} \cdot \frac{60\,sec}{1\,min} = 36000\ sec$

200 BTU/sec

~~12,015 BTU/min~~

~~720,100 BTU/hr~~

if 100%

Double probably

Needs to melt how fast?

$5.59\,m / 36{,}000\,sec = .0001553\ m/sec$

Melt rate ⇒ $.1553\ mm/sec$

$\frac{200\ BTU/sec}{.1553\ mm/sec} = 1{,}288\ BTU/mm$ per thickness of 1 mm

Volume of that thickness

$.003373\ m^3$

How much H_2O needed at 85 °F to melt 1 mm thickness

$1{,}288\ BTU \cdot \frac{1\ kcal}{4.25\ BTU} = x \cdot \rho \cdot C_p \cdot (T_2 - T_2)$

$303.06\ kcal = x \cdot \rho \cdot C_p \cdot (T_2 - T_1)$

B

$303{,}059\ cal = x \cdot \rho\ C_p \cdot (T_2 - T_1)$

$C_p = .998\ cal/g \cdot {}^\circ C \qquad \rho = 985\ kg/m^3$

$T_2 = 80^\circ C \qquad T_1 = 30^\circ C$

$\Delta T = 50^\circ C$

$303{,}059\ cal = \cancel{X} \cdot (983\ kcal/m^3 \cdot {}^\circ C)(\Delta T)$

$X \cdot (49{,}151.5\ kcal/m^3)$

$X \cdot (49{,}151{,}500\ cal/m^3)$

$X = .0061658\ m^3\ H_2O$ at $80^\circ C$

$264.2\ gal = 1\ m^3$

$.0061658\ m^3 \cdot \frac{264.2\ gal}{1\ m^3} = \boxed{1.629\ gal}$ at $80^\circ C$

for 1 mm thickness

Melt rate $= .1553\ mm/sec$

$= 6.44\ sec/mm$

$\frac{1.63\ gal}{6.44\ sec} = .253\ gal/sec$

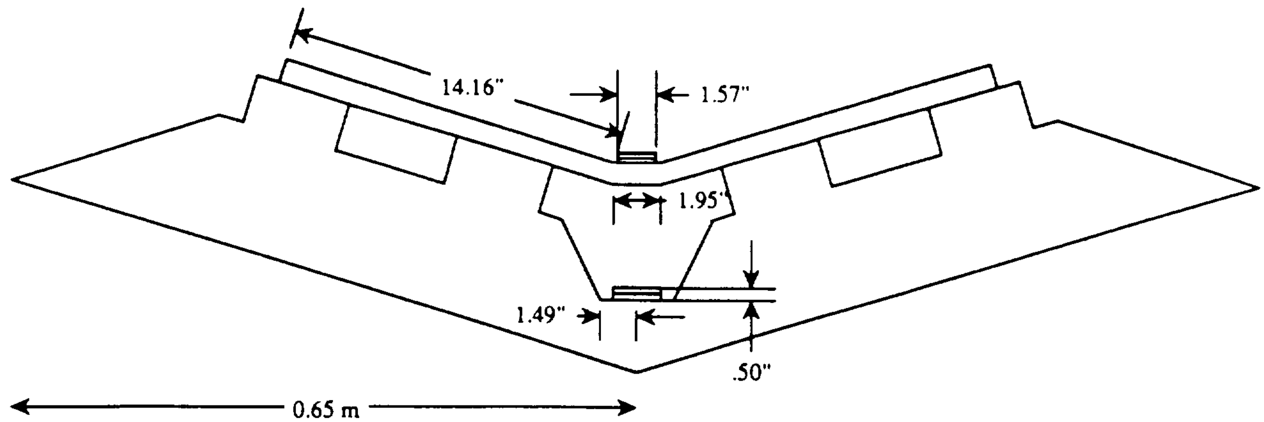
$.253\ gal/sec \cdot \frac{60\ sec}{min} \cdot \frac{60\ min}{hr}$

$911.2\ gal/hr$

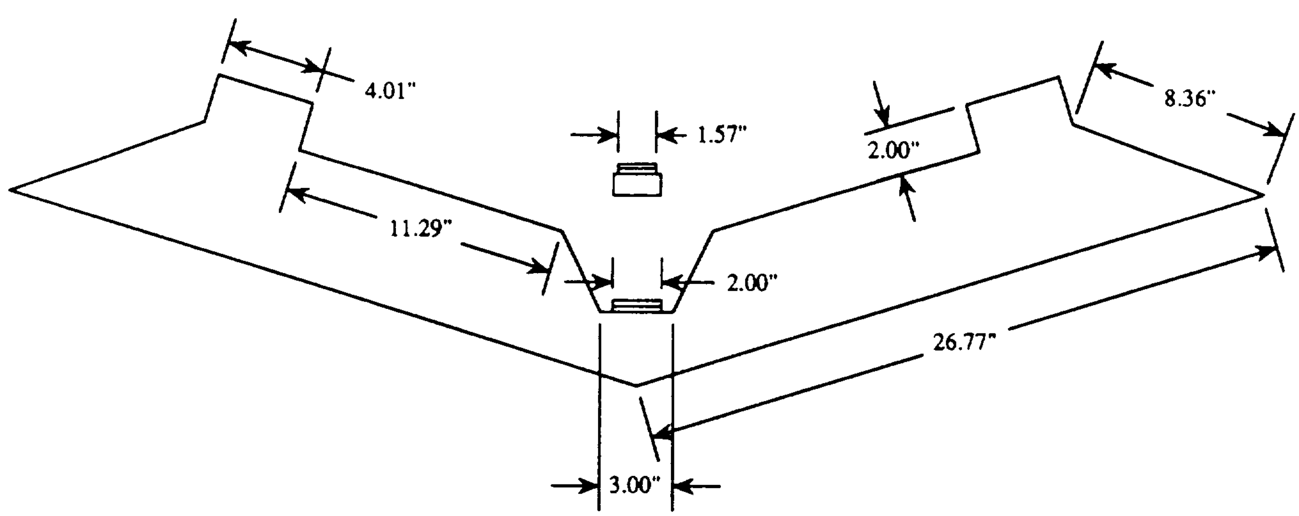
$\boxed{15.2\ gal/min}$

If 100% efficient

Appendix C



Side View of Icemelter



Side View of Icemelter Rotated30 degrees

C

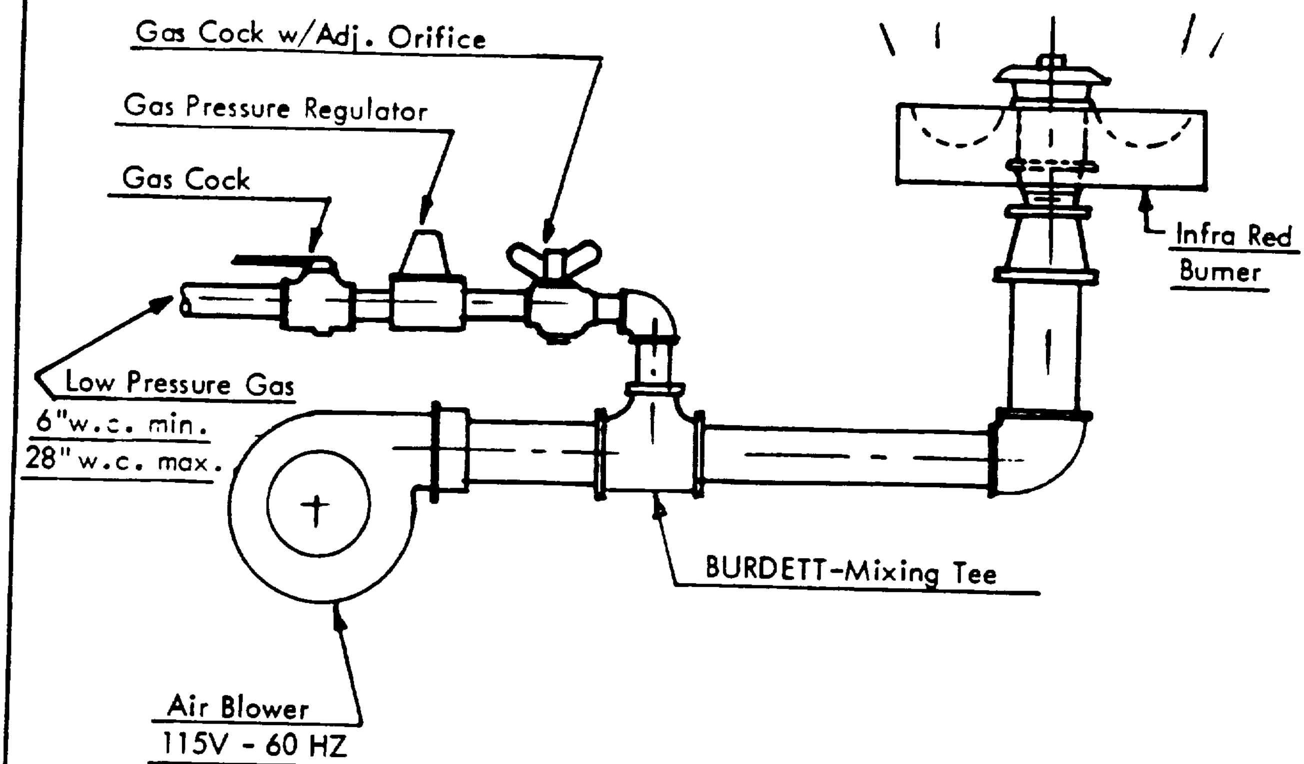
	A	B	C	D	E	F	G	H	I
1									
2				**Weight**					
3									
4									
5									
6	John Muhlner								
7	2-Aug-90								
8									
9	Burner System:								
10		Cup 21				Amount Needed		Weight (lbs)	
11		Cups with refractory		1.00	lbs/each	18.00	cups	18.00	
12		Ignition Tubes		0.80	lbs/ft	0.00	ft	0.00	
13		Burner Manifold		3.00	lbs/ft	13.29	ft	39.87	
14		Spark Ignighter		0.50	lb/each	0.00	Ignitters	0.00	
15	Surface Equipment:								
16		Mixing Blower		60.00	lbs	1.00		60.00	
17		Mixing T		15.00	lbs	1.00		15.00	
18		Gass Pressure Regulator		5.00	lbs	1.00		5.00	
19		Gas Cock		5.00	lbs	2.00		10.00	
20									
21		Air Blower		80.00	lbs	1.00		80.00	
22		Gas Distributer		0.09	lbs	1.00		0.09	
23		Air Distributer		0.11	lbs	1.00		0.11	
24									
25		Flexible Tubing		30.00	lbs	1.00		30.00	
26		Genarator		125.00	lbs	1.00		125.00	
27		Pump		5.00	lbs	1.00		5.00	
28		Tri pod		30.00	lbs	1.00		30.00	
29	Cone:								
30		Radius		0.65	m				
31		Height		0.20	m				
32		Surface Area		1.3887	m^2				
33		Thickness		0.25	in				
34				0.006350	m				
35		Density	Steel 347	7978.00	Kg/m^3				
36		Volume		0.008818	m^3	1.00	Sheild	155.10	
37	Top plate:								
38		Density	Steel 347	7978.00	Kg/m^3				
39		Surface Area		0.8029	m^2				
40		Thickness		0.25	in				
41				0.006350	m				
42		Volume		0.0051	m^3	1.00	plate	89.67	
43									
44	Weight:								
45		Sub Total of Cavity		244.77	lbs				
46		Needed Weight		287.00	lbs				
47									
48	Fuel:								
49		Propane Bottle		180.00		4.00		720.00	
50									
51	Miscelaneous:								
52		Miscellaneous		50.00				50.00	
53									
54									
55			Total Weight					1432.84	lbs
56									
57			Weight in Melter					302.84	lbs

C

	A	B	C	D	E	F	G	H
1								
2				Volume of Cavity				
3								
4								
5	John Muhlner							
6	08-15-90							
7								
8	**Inputs:**							
9		Cone:		Volume = 1/3*π*r^2*h				
10				Surface Area = π*r(r^2+h^2)^.5				
11								
12		Cylinder:		Volume = π*r^2*h				
13				Surface Area = 2*π*r*h				
14								
15		Circle:		Surface Area = π*r^2				
16								
17				radius	height	Volume (m^3)	Surface Area (m^2)	
18		Cone #	1	0.6500	0.2000	0.0885	1.3887	
19			2	0.4500	0.1400	0.0297	0.6662	
20			3	0.0800	0.0267	0.0002	0.0212	
21			4	0.0800	0.1600	0.0011	0.0450	
22			5	0.0400	0.0767	0.0001	0.0109	
23								
24		Cylinder	1	0.6500	0.0733	0.0973	0.2994	
25			2	0.4500	0.0733	0.0466	0.2073	
26			3	0.0508	0.0508	0.0004	0.0162	
27								
28		Circle #	1	0.0400			0.0050	
29			2	0.0254			0.0020	
30								
31		Outside:					0.1208	
32								
33	**Calculations:**							
34		Total Volume = Cone1 + Cylinder2 + (Cylinder1-2)/2 - Cone2 +Cone3 - Cone4+ Cone3						
35				+Cone5				
36		Surface Area of top plate = outside + Cone2 - Cone3 + Cone4 - Cone5 + Circle1- Circle2						
37								
38				Total Volume =			0.1302	m^3
39				Surface Area of Plate =			0.8029	m^2
40								
41								
42		Weight of system needs to be:						
43			Density of Water =		1000.00	Kg/m^3		
44			Total Weight = Total Volue * Density of Water				130.18	Kg
45				1 Kg = 2.2046 lbs			286.99	lbs

C

BURDETT ENGINEERING DATA SHEET No. RH - 1



BURDETT RADIANT HEATER

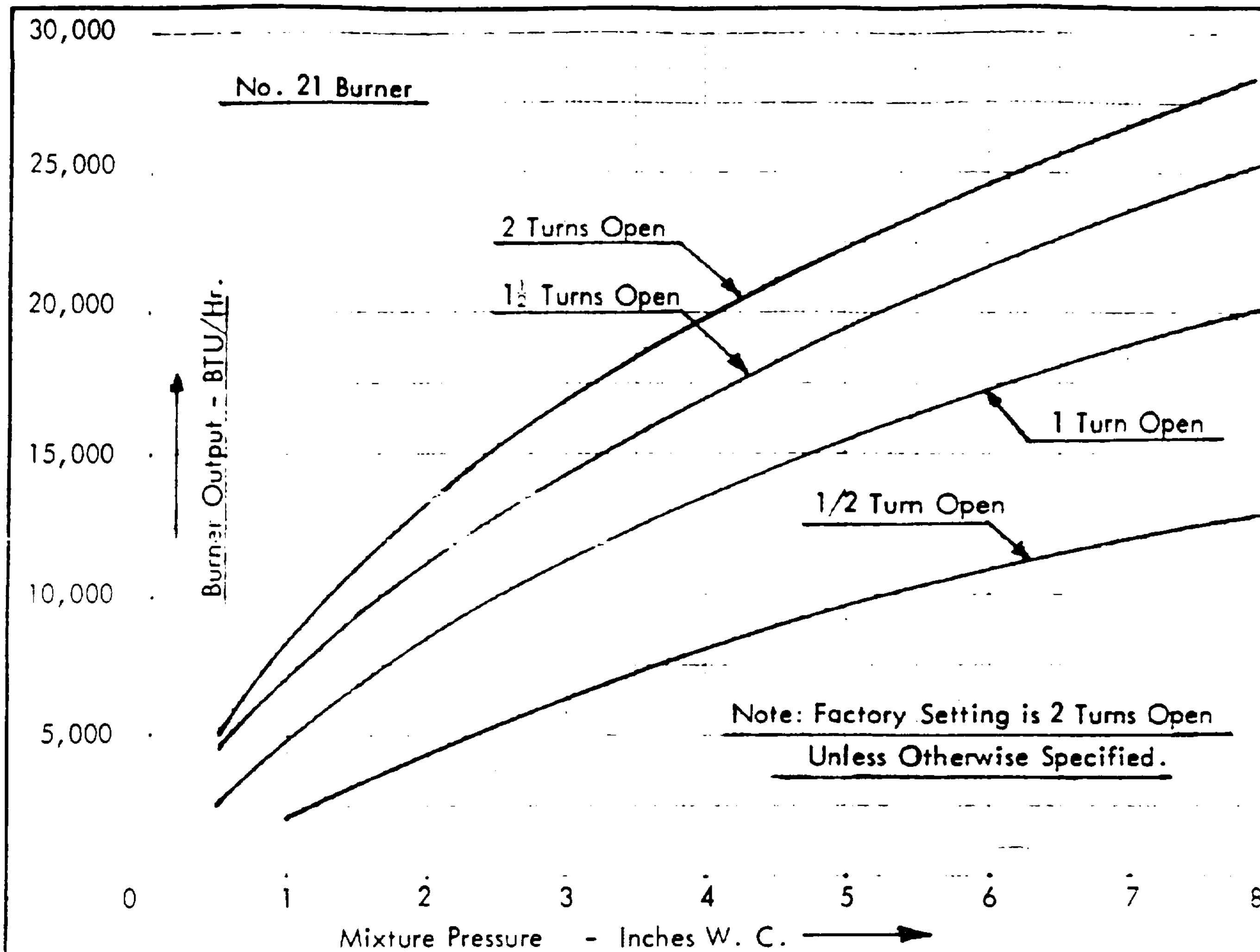
The BURDETT Radiant Heater is a small conveniently packaged system for providing intense radiant heat.

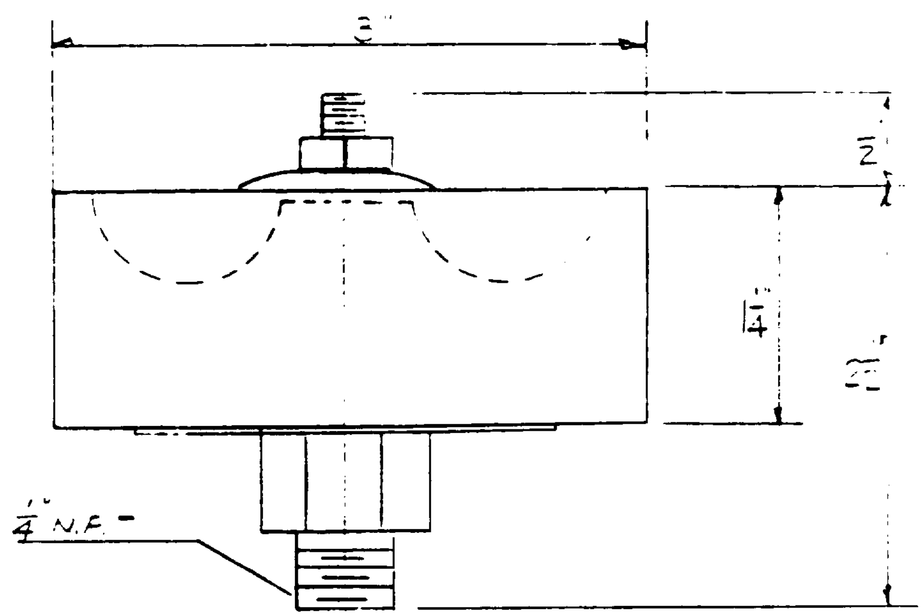
It is inexpensive to purchase, economical, and simple to operate. It utilizes a small air blower and low pressure gas for its operation.

The Radiant Heaters are available in sizes ranging from 10,000 BTU/Hr up to 140,000 BTU/Hr.

July 11, 1988

BURDETT ENGINEERING DATA SHEET No. C-1

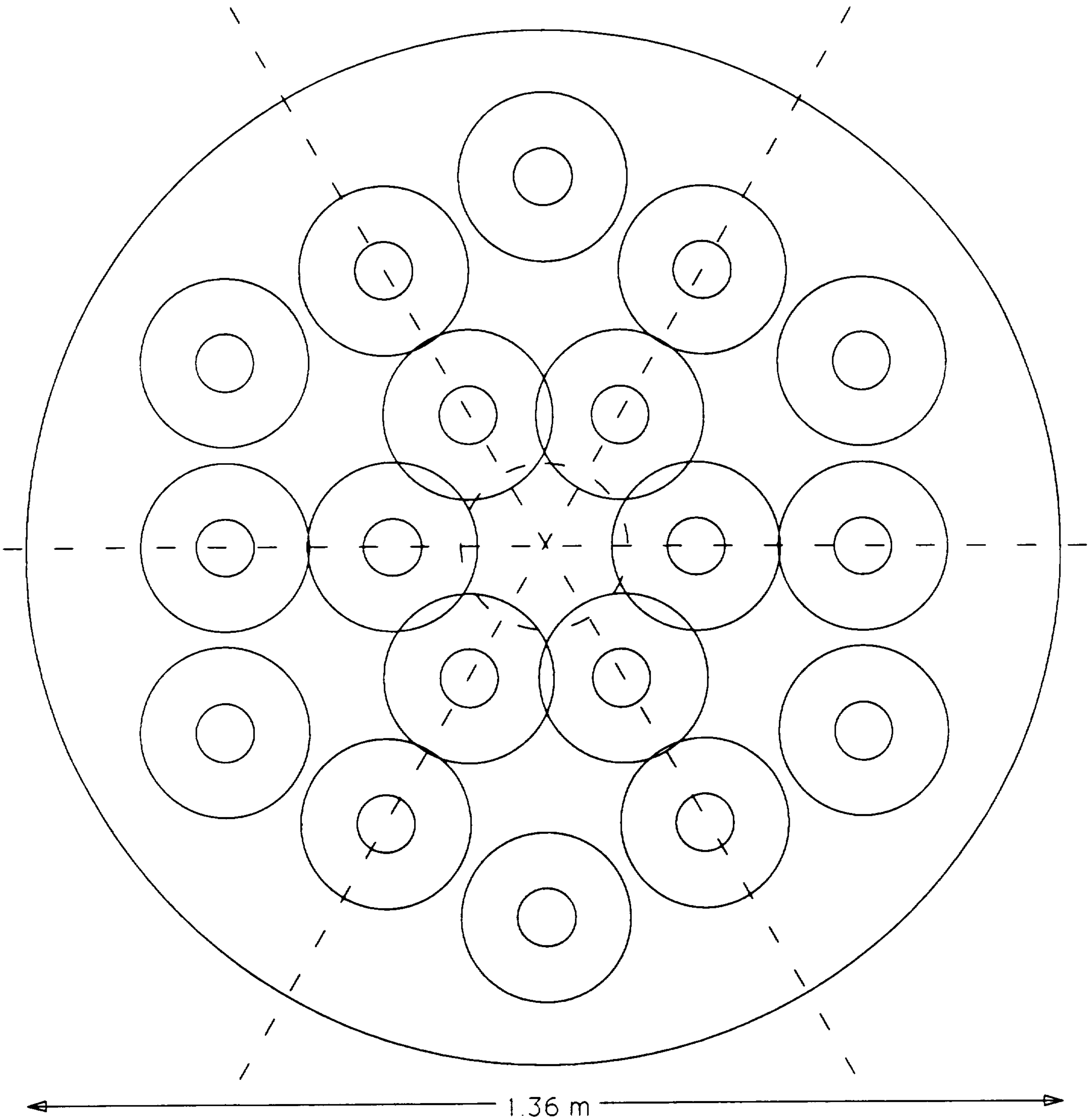


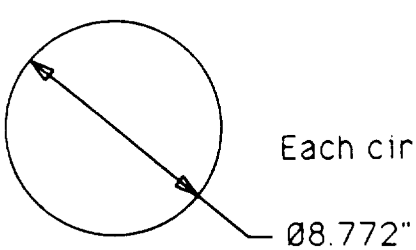


No. 21S Burner

C

Projection of Burners and Radiant Heat on Cone Surface

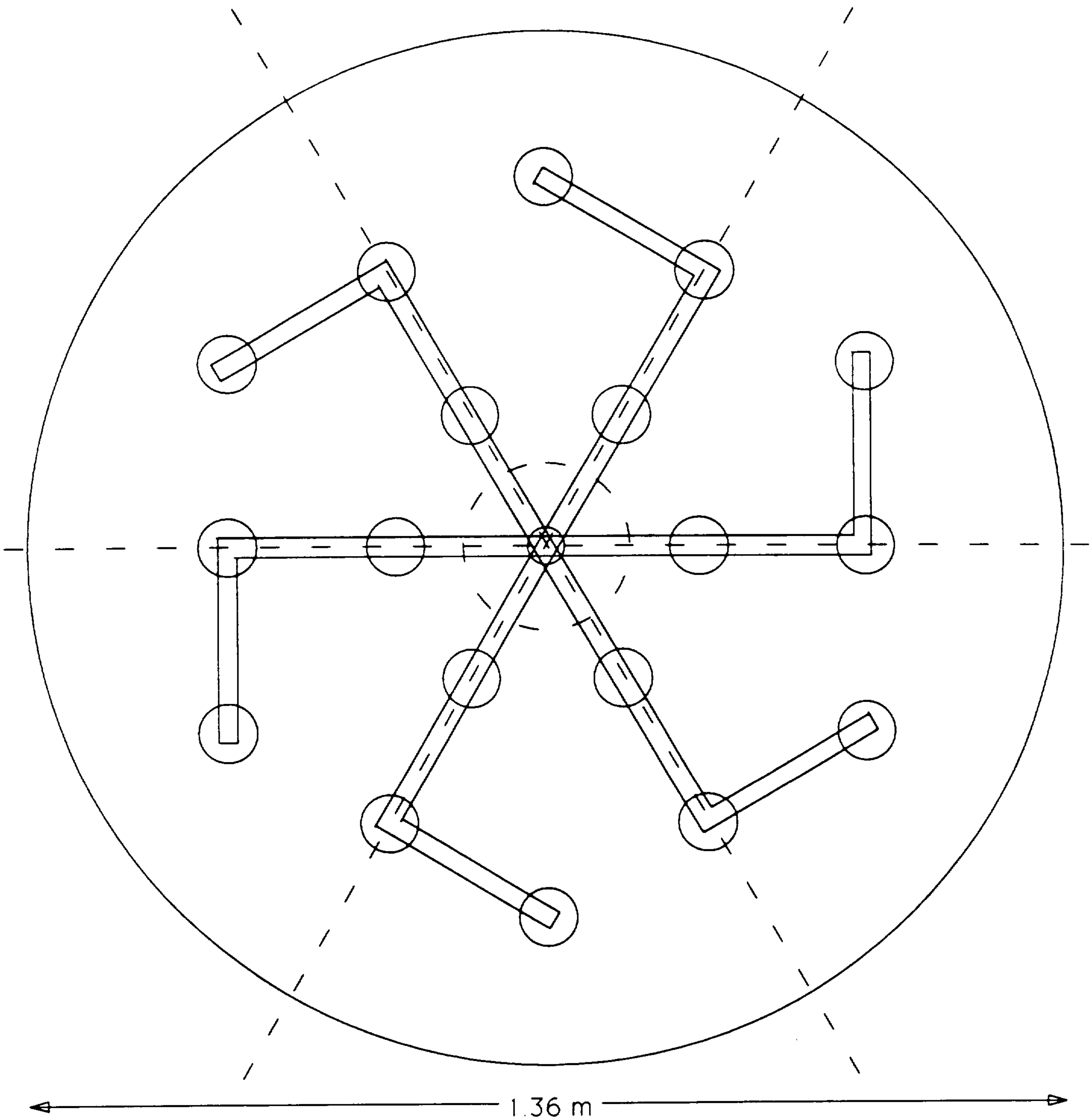


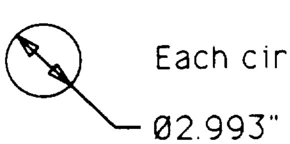


Each circle represennts the area a burner radiates heat

C

Manifold Layout





Each circle represennts a burner

C

Total Energy Needed

	A	B	C	D	E	F	G
1	Total Energy Needed						
2							
3							
4	Ice Melter project						
5	3-Jul-90						
6							
7	**Inputs:**						
8		Diameter	1.30	m	Cp:	cal/g degree C	Temp degrees C
9		Diameter-2	0.2286	m			
10		Depth	4.20	m		0.392	-60.00
11		Depth-2	3.90				
12		Volume	5.57	m^3		0.4454	-31.80
13		Volume-2	0.16	m^3			
14		Density (Ice)	989.59	Kg/m^3		0.5018	-2.20
15		Temperature	0 to -50	degrees C		0.4583	-25.00
16			-25.00	avg degrees C		0.4585	-25.00
17		Cp	0.4584	cal/g degree C			
18		Heat Fusion (L)	79.50	cal/g			
19							
20	**Conversions:**						
21		4.25 BTU = Kcal					
22							
23		Kcal = 1 Kg/1 degree C					
24							
25		1054.35 J = 1 BTU					
26							
27	**Calculations:**						
28		Total Volume			V =	5.41	m^3
29			Volume1 - Volmue2 = Total Volume				
30							
31		Mass of the Ice			M =	5358.51	Kg (Ice)
32			M = Volume * Density				
33							
34		Energy of heating			Qc =	61406155.01	cal
35			Qc = Cp*M * (T2-T1)				
36							
37		Energy of Fusion			Qp =	426001609.20	cal
38			Qf = L * M				
39							
40		Total Energy			Qt =	487407764.21	cal
41			Qt = Qc + Qp				
42							
43		Energy in BTU's			E(t) =	2071483.00	BTU
44							
45		Energy in Joules			E(t) =	2.18E+09	Joules
46							
47							
48			Total Energy = 2071500 BTU				
49							
50							
51							
52							
53							
54							
55							
56							
57							
58							

C

	A	B	C	D	E	F	G	H	I	J
1										
2	**Infared Burners**									
3										
4										
5	John Muhlner									
6	08-01-90									
7										
8	**Specifications:**									
9		Characteristics of Copper and Stainless Steel								
10			Metal	Kind		Emissivity at °K / Thermal Conductivity				
11						600	800	1000		
12			Copper	Stably Oxidized		0.50	0.58	0.80		
13						379	366	352	W/m*K	
14										
15			Comercial Bronze	(90% Cu & 10% Al)		?	?	?		
16						?	?	?		
17										
18			Stainless Steel	Highly Oxidized		0.63	0.67	0.70		
19										
20				AISI 347 Stably Oxidized		0.87	0.88	0.89		
21						18.9	21.9	24.7	W/m*K	
22										
23										
24		Burners		Radiant Heat	4in W.C.	6in W.C.	8in W.	(BTU/hr)		
25			10-L Series:							
26				55-60%	34500	43000	50000		12in long each	
27										
28			Cup Series							
29			21:	40%	20000	25000			4 per foot	
30			30:	40%	50000	62000			3 per foot	
31										
32										
33		Environment Temperature Desired			1000	°F		500	°F	
34					537.78	°C		260	°C	
35					810.93	K		533	K	
36			Conduction at this Temp		8110	BTU/hr-ft^2		1575	BTU/hr-ft^2	
37				(Calculations for this)		????????				
38										
39										
40		Surface Area of Cone				S.A. =	πr(r^2+h^2)	=	1.3887	m^2
41			Radius	0.65	m				14.95	ft^2
42			Height	0.20	m					
43			Angle	17.10	°					
44									BTU	
45		Total Energy Needed to melt ice:				ideally		q=	2158031.00	
46					0.50	efficiency		q=	4316062.00	
47										
48		Propane								
49			1 gallon =	91500.00	BTU					
50			24 gallons =	1.00	bottle					
51			1 bottle =	180.00	lbs					
52										
53										
54										
55										

C

	A	B	C	D	E	F	G	H	I	J
56	Inputs:									
57		Type of Burner		Cup 21						
58			Pressure	6.00	in W.C.					
59			BTU rate	25000	BTU/hr					
60			% Radiant Heat	0.40						
61										
62		Number of Burners		18	Burners					
63										
64		Type of Metal		Steel 347						
65			Absorbtion Coef	0.89						
66			Thickness (L)	0.25	in					
67				0.006350	m					
68			Conduction (k)	24.70	W/m*K					
69										
70		External Temperature		-20.00	°C					
71				-4.00	°F					
72		Desired Internal Temp		1000	°F					
73				811	K					
74			Conduction Coef	8110	BTU/hr-ft^2					
75										
76		Conversion Factor		1.10	(Due to density of air and other things)					
77		Absolute Zero Temp		465	°F					
78										
79	Calculations:									
80		Energy to Metal Surface								
81			BTU rate from burners = # of burners * BTU rate per burner							
82							Rate =	450000	BTU/hr	
83										
84			Energy rate at S.A.= (%radiant heat*BTU rate from burners*absorbtion Coef of metal+							
85				Conduction Coef of heat * Surface Area)						
86				q rad =	160200		q =	281431	BTU/hr	
87				q con =	121231					
88			Time to melt ice = Total Energy needed / Energy rate at S.A.							
89							T =	15.34	hrs	
90										
91			Temperature outside of S.A. = Temp inside S.A. - (q*L)/(k*S.A.)							
92							Tout =	758.83	K	
93								485.68	°C	
94								906.22	°F	
95										
96			Sensible heat = BTU rate from burners - Energy rate at S.A.							
97							q(S.H.)	168569	BTU/hr	
98										
99			SCFM 70°F = Sensible heat / (conversion factor *(Internal temperature °F - 70°F))							
100							SCFM =	164.78	ft^3/min	
101										
102			SCFM Ex Temp = (SCFM 70°F)(Absolute Zero+Ex Temp)/(Absolute Zero+Stan Temp)							
103							SCFM =	141.99	ft^3/min	
104										
105			Total amount of BTU = BTU rate of burners * Hours					Q =	6.90E+06	BTU
106										
107			Bottles of Propane = Total amount of BTU /91500/24					Bottles =	3.14	
108										
109			Weight = # of Bottles * 180lbs					Weight =	565.68	lbs
110										

<

	A	B	C	D	E	F	G	H	I	J
111										
112										
113			50% efficiency Cup 21 6in 347 1000°F							
114										
115	Table of Calculations									
116		# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles		Weight (lbs)	
117		2	50000	139031	1552195	31.0	hr	0.71	127.23	
118		4	100000	156831	2752048	27.5	hr	1.25	225.58	
119		6	150000	174631	3707301	24.7	hr	1.69	303.88	
120		8	200000	192431	4485831	22.4	hr	2.04	367.69	
121		10	250000	210231	5132526	20.5	hr	2.34	420.70	
122		12	300000	228031	5678260	18.9	hr	2.59	465.43	
123		14	350000	245831	6144963	17.6	hr	2.80	503.69	
124		16	400000	263631	6548644	16.4	hr	2.98	536.77	
125		18	450000	281431	6901261	15.3	hr	3.14	565.68	
126		20	500000	299231	7211926	14.4	hr	3.28	591.14	
127		22	550000	317031	7487706	13.6	hr	3.41	613.75	
128		24	600000	334831	7734165	12.9	hr	3.52	633.95	
129		26	650000	352631	7955742	12.2	hr	3.62	652.11	
130		28	700000	370431	8156025	11.7	hr	3.71	668.53	

	A	B	C	D	E	F	G	H	I
117			50% efficiency Cup 21 6in 347 1000°F						
118									
119	Table of Calculations								
120		# Burners /	Rate	q at S.A.	Total BTU	Time (hr)		# of Bottles	Weight (lbs)
121		2	50000	146356	1474512	29.5	hr	0.67	120.86
122		4	100000	164156	2629251	26.3	hr	1.20	215.51
123		6	150000	181956	3558063	23.7	hr	1.62	291.64
124		8	200000	199756	4321344	21.6	hr	1.97	354.21
125		10	250000	217556	4959724	19.8	hr	2.26	406.53
126		12	300000	235356	5501542	18.3	hr	2.51	450.95
127		14	350000	253156	5967168	17.0	hr	2.72	489.11
128		16	400000	270956	6371616	15.9	hr	2.90	522.26
129		18	450000	288756	6726201	14.9	hr	3.06	551.33
130		20	500000	306556	7039608	14.1	hr	3.21	577.02
131		22	550000	324356	7318617	13.3	hr	3.33	599.89
132		24	600000	342156	7568596	12.6	hr	3.45	620.38
133		26	650000	359956	7793852	12.0	hr	3.55	638.84
134		28	700000	377756	7997879	11.4	hr	3.64	655.56

	A	B	C	D	E	F	G	H	I
117			50% efficiency Cup 21 4in Steel 347 1000°F						
118									
119	Table of Calculations								
120		# Burners /	Rate	q at S.A.	Total BTU	Time (hr)		# of Bottles	Weight (lbs)
121		2	40000	142796	1209019	30.2	hr	0.55	99.10
122		4	80000	157036	2198769	27.5	hr	1.00	180.23
123		6	120000	171276	3023942	25.2	hr	1.38	247.86
124		8	160000	185516	3722437	23.3	hr	1.70	305.12
125		10	200000	199756	4321344	21.6	hr	1.97	354.21
126		12	240000	213996	4840544	20.2	hr	2.20	396.77
127		14	280000	228236	5294956	18.9	hr	2.41	434.01
128		16	320000	242476	5695996	17.8	hr	2.59	466.88
129		18	360000	256716	6052544	16.8	hr	2.76	496.11
130		20	400000	270956	6371616	15.9	hr	2.90	522.26
131		22	440000	285196	6658825	15.1	hr	3.03	545.81
132		24	480000	299436	6918716	14.4	hr	3.15	567.11
133		26	520000	313676	7155011	13.8	hr	3.26	586.48
134		28	560000	327916	7370784	13.2	hr	3.36	604.16

	A	B	C	D	E	F	G	H	I
117			50% efficiency Cup 21 6in Cu 1000°F						
118									
119	Table of Calculations								
120		# Burners /	Rate	q at S.A.	Total BTU	Time (hr)		# of Bottles	Weight (lbs)
121		2	50000	144556	1492873	29.9	hr	0.68	122.37
122		4	100000	160556	2688205	26.9	hr	1.22	220.34
123		6	150000	176556	3666887	24.4	hr	1.67	300.56
124		8	200000	192556	4482926	22.4	hr	2.04	367.45
125		10	250000	208556	5173756	20.7	hr	2.36	424.08
126		12	300000	224556	5766139	19.2	hr	2.63	472.63
127		14	350000	240556	6279721	17.9	hr	2.86	514.73
128		16	400000	256556	6729243	16.8	hr	3.06	551.58
129		18	450000	272556	7125989	15.8	hr	3.24	584.10
130		20	500000	288556	7478736	15.0	hr	3.41	613.01
131		22	550000	304556	7794420	14.2	hr	3.55	638.89
132		24	600000	320556	8078591	13.5	hr	3.68	662.18
133		26	650000	336556	8335742	12.8	hr	3.80	683.26
134		28	700000	352556	8569553	12.2	hr	3.90	702.42

C

	A	B	C	D	E	F	G	H	I	J
117			50% efficiency Cup 21 4in Steel 347 500°F							
118										
119	Table of Calculations									
120		# Burners /	Rate	q at S.A.	Total BTU	Time (hr)		# of Bottles	Weight (lbs)	
121		2	40000	40080	4307494	107.7hr		1.96	353.07	
122		4	80000	54000	6394218	79.9hr		2.91	524.12	
123		6	120000	67920	7625600	63.5hr		3.47	625.05	
124		8	160000	81840	8438094	52.7hr		3.84	691.65	
125		10	200000	95760	9014373	45.1hr		4.10	738.88	
126		12	240000	109680	9444375	39.4hr		4.30	774.13	
127		14	280000	123600	9777521	34.9hr		4.45	801.44	
128		16	320000	137520	10043225	31.4hr		4.57	823.22	
129		18	360000	151440	10260082	28.5hr		4.67	840.99	
130		20	400000	165360	10440429	26.1hr		4.75	855.77	
131		22	440000	179280	10592771	24.1hr		4.82	868.26	
132		24	480000	193200	10723160	22.3hr		4.88	878.95	
133		26	520000	207120	10836023	20.8hr		4.93	888.20	
134		28	560000	221040	10934670	19.5hr		4.98	896.28	

	A	B	C	D	E	F	G	H	I	J
117			50% efficiency Cup 21 4in Cu							
118										
119	Table of Calculations									
120		# Burners /	Rate	q at S.A.	Total BTU	Time (hr)		# of Bottles	Weight (lbs)	
121		2	40000	141356	1221335	31hr		0.56	100.11	
122		4	80000	154156	2239848	28hr		1.02	183.59	
123		6	120000	166956	3102187	26hr		1.41	254.28	
124		8	160000	179756	3841717	24hr		1.75	314.89	
125		10	200000	192556	4482926	22hr		2.04	367.45	
126		12	240000	205356	5044202	21hr		2.30	413.46	
127		14	280000	218156	5539613	20hr		2.52	454.07	
128		16	320000	230956	5980111	19hr		2.72	490.17	
129		18	360000	243756	6374346	18hr		2.90	522.49	
130		20	400000	256556	6729243	17hr		3.06	551.58	
131		22	440000	269356	7050410	16hr		3.21	577.90	
132		24	480000	282156	7342438	15hr		3.34	601.84	
133		26	520000	294956	7609120	15hr		3.46	623.70	
134		28	560000	307756	7853618	14hr		3.58	643.74	

C

	A	B	C	D	E	F	G	H	I	J
117			50% efficiency Cup 21 6in Cu 347 500°F							
118										
119	Table of Calculations									
120		# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles		Weight (lbs)	
121		2	50000	36160	5968078	119.4hr		2.72	489.19	
122		4	100000	46160	9350310	93.5hr		4.26	766.42	
123		6	150000	56160	11528033	76.9hr		5.25	944.92	
124		8	200000	66160	13047432	65.2hr		5.94	1069.46	
125		10	250000	76160	14167827	56.7hr		6.45	1161.30	
126		12	300000	86160	15028147	50.1hr		6.84	1231.82	
127		14	350000	96160	15709532	44.9hr		7.15	1287.67	
128		16	400000	106160	16262546	40.7hr		7.41	1333.00	
129		18	450000	116160	16720345	37.2hr		7.61	1370.52	
130		20	500000	126160	17105568	34.2hr		7.79	1402.10	
131		22	550000	136160	17434208	31.7hr		7.94	1429.03	
132		24	600000	146160	17717877	29.5hr		8.07	1452.29	
133		26	650000	156160	17965216	27.6hr		8.18	1472.56	
134		28	700000	166160	18182784	26.0hr		8.28	1490.39	

	A	B	C	D	E	F	G	H	I	J
117			50% efficiency Cup 21 6in Steel 347 500°F							
118										
119	Table of Calculations									
120		# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles		Weight (lbs)	
121		2	50000	43560	4954207	99.1hr		2.26	406.08	
122		4	100000	60960	7080205	70.8hr		3.22	580.34	
123		6	150000	78360	8262033	55.1hr		3.76	677.22	
124		8	200000	95760	9014373	45.1hr		4.10	738.88	
125		10	250000	113160	9535345	38.1hr		4.34	781.59	
126		12	300000	130560	9917455	33.1hr		4.52	812.91	
127		14	350000	147960	10209693	29.2hr		4.65	836.86	
128		16	400000	165360	10440429	26.1hr		4.75	855.77	
129		18	450000	182760	10627230	23.6hr		4.84	871.08	
130		20	500000	200160	10781553	21.6hr		4.91	883.73	
131		22	550000	217560	10911192	19.8hr		4.97	894.36	
132		24	600000	234960	11021629	18.4hr		5.02	903.41	
133		26	650000	252360	11116838	17.1hr		5.06	911.22	
134		28	700000	269760	11199764	16.0hr		5.10	918.01	

	A	B	C	D	E	F	G	H	I	J
117			50% efficiency Cup 21 4in Cu 500°F							
118										
119	Table of Calculations									
120		# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles		Weight (lbs)	
121		2	40000	34160	5054002	126.4hr		2.30	414.26	
122		4	80000	42160	8189956	102.4hr		3.73	671.31	
123		6	120000	50160	10325597	86.0hr		4.70	846.36	
124		8	160000	58160	11873713	74.2hr		5.41	973.26	
125		10	200000	66160	13047432	65.2hr		5.94	1069.46	
126		12	240000	74160	13967921	58.2hr		6.36	1144.91	
127		14	280000	82160	14709150	52.5hr		6.70	1205.67	
128		16	320000	90160	15318839	47.9hr		6.98	1255.64	
129		18	360000	98160	15829149	44.0hr		7.21	1297.47	
130		20	400000	106160	16262546	40.7hr		7.41	1333.00	
131		22	440000	114160	16635201	37.8hr		7.58	1363.54	
132		24	480000	122160	16959047	35.3hr		7.72	1390.09	
133		26	520000	130160	17243084	33.2hr		7.85	1413.37	

C

117 **50% efficiency 10-LS 6in 347 500°F**

119 Table of Calculations

Row	# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles	Weight (lbs)
121	2	86000	71052	5224112	60.7 hr	2.38	428.21
122	4	172000	115944	6402793	37.2 hr	2.92	524.82
123	6	258000	160836	6923494	26.8 hr	3.15	567.50
124	8	344000	205728	7216949	21.0 hr	3.29	591.55
125	10	430000	250620	7405275	17.2 hr	3.37	606.99
126	12	516000	295512	7536382	14.6 hr	3.43	617.74
127	14	602000	340404	7632909	12.7 hr	3.48	625.65
128	16	688000	385296	7706942	11.2 hr	3.51	631.72
129	18	774000	430188	7765524	10.0 hr	3.54	636.52
130	20	860000	475080	7813035	9.1 hr	3.56	640.41
131	22	946000	519972	7852342	8.3 hr	3.58	643.63
132	24	1032000	564864	7885402	7.6 hr	3.59	646.34
133	26	1118000	609756	7913593	7.1 hr	3.60	648.66
134	28	1204000	654648	7937918	6.6 hr	3.61	650.65

117 **50% efficiency 10-LS 6in Cu 500°F**

119 Table of Calculations

Row	# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles	Weight (lbs)
121	2	86000	51960	7143658	83.1 hr	3.25	585.55
122	4	172000	77760	9546899	55.5 hr	4.35	782.53
123	6	258000	103560	10752691	41.7 hr	4.90	881.37
124	8	344000	129360	11477507	33.4 hr	5.23	940.78
125	10	430000	155160	11961278	27.8 hr	5.45	980.43
126	12	516000	180960	12307103	23.9 hr	5.60	1008.78
127	14	602000	206760	12566622	20.9 hr	5.72	1030.05
128	16	688000	232560	12768560	18.6 hr	5.81	1046.60
129	18	774000	258360	12930166	16.7 hr	5.89	1059.85
130	20	860000	284160	13062426	15.2 hr	5.95	1070.69
131	22	946000	309960	13172669	13.9 hr	6.00	1079.73
132	24	1032000	335760	13265969	12.9 hr	6.04	1087.37
133	26	1118000	361560	13345954	11.9 hr	6.08	1093.93
134	28	1204000	387360	13415284	11.1 hr	6.11	1099.61

117 **50% efficiency 10-LS 6in 347 500°F**

119 Table of Calculations

Row	# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles	Weight (lbs)
121	2	86000	71052	5224112	60.7 hr	2.38	428.21
122	4	172000	115944	6402793	37.2 hr	2.92	524.82
123	6	258000	160836	6923494	26.8 hr	3.15	567.50
124	8	344000	205728	7216949	21.0 hr	3.29	591.55
125	10	430000	250620	7405275	17.2 hr	3.37	606.99
126	12	516000	295512	7536382	14.6 hr	3.43	617.74
127	14	602000	340404	7632909	12.7 hr	3.48	625.65
128	16	688000	385296	7706942	11.2 hr	3.51	631.72
129	18	774000	430188	7765524	10.0 hr	3.54	636.52
130	20	860000	475080	7813035	9.1 hr	3.56	640.41
131	22	946000	519972	7852342	8.3 hr	3.58	643.63
132	24	1032000	564864	7885402	7.6 hr	3.59	646.34
133	26	1118000	609756	7913593	7.1 hr	3.60	648.66

C

50% efficiency 10-LS 4in 347 1000°F

Table of Calculations

Row	# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles	Weight (lbs)
121	2	69000	165402	1800517	26.1 hr	0.82	147.58
122	4	138000	202248	2944988	21.3 hr	1.34	241.39
123	6	207000	239094	3736716	18.1 hr	1.70	306.29
124	8	276000	275940	4317007	15.6 hr	1.97	353.85
125	10	345000	312786	4760582	13.8 hr	2.17	390.21
126	12	414000	349632	5110665	12.3 hr	2.33	418.91
127	14	483000	386478	5393995	11.2 hr	2.46	442.13
128	16	552000	423324	5628003	10.2 hr	2.56	461.31
129	18	621000	460170	5824537	9.4 hr	2.65	477.42
130	20	690000	497016	5991931	8.7 hr	2.73	491.14
131	22	759000	533862	6136218	8.1 hr	2.79	502.97
132	24	828000	570708	6261875	7.6 hr	2.85	513.27
133	26	897000	607554	6372290	7.1 hr	2.90	[illegible]

50% efficiency 10-LS 6in 347 1000°F

Table of Calculations

Row	# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles	Weight (lbs)
121	2	86000	174480	2127363	24.7 hr	0.97	174.37
122	4	172000	220404	3368197	19.6 hr	1.53	276.08
123	6	258000	266328	4181107	16.2 hr	1.90	342.71
124	8	344000	312252	4754901	13.8 hr	2.17	389.75
125	10	430000	358176	5181556	12.1 hr	2.36	424.72
126	12	516000	404100	5511236	10.7 hr	2.51	451.74
127	14	602000	450024	5773630	9.6 hr	2.63	473.25
128	16	688000	495948	5987429	8.7 hr	2.73	490.77
129	18	774000	541872	6164989	8.0 hr	2.81	505.33
130	20	860000	587796	6314803	7.3 hr	2.88	517.61
131	22	946000	633720	6442905	6.8 hr	2.93	528.11
132	24	1032000	679644	6553694	6.4 hr	2.98	537.19
133	26	1118000	725568	6650459	5.9 hr	3.03	545.12
134	28	1204000	771492	6735704	5.6 hr	3.07	552.11

50% efficiency 10-LS 4in 347 500°F

Table of Calculations

Row	# Burners /	Rate	q at S.A.	Total BTU	Time (hr)	# of Bottles	Weight (lbs)
121	2	69000	62178	4789642	69.4 hr	2.18	392.59
122	4	138000	98196	6065616	44.0 hr	2.76	497.18
123	6	207000	134214	6656740	32.2 hr	3.03	545.63
124	8	276000	170232	6997722	25.4 hr	3.19	573.58
125	10	345000	206250	7219610	20.9 hr	3.29	591.77
126	12	414000	242268	7375522	17.8 hr	3.36	604.55
127	14	483000	278286	7491075	15.5 hr	3.41	614.02
128	16	552000	314304	7580144	13.7 hr	3.45	621.32
129	18	621000	350322	7650898	12.3 hr	3.48	627.12
130	20	690000	386340	7708459	11.2 hr	3.51	631.84
131	22	759000	422358	7756203	10.2 hr	3.53	635.75
132	24	828000	458376	7796444	9.4 hr	3.55	639.05
133	26	897000	494394	7830821	8.7 hr	3.57	641.87
134	28	966000	530412	7860530	8.1 hr	3.58	644.31

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C

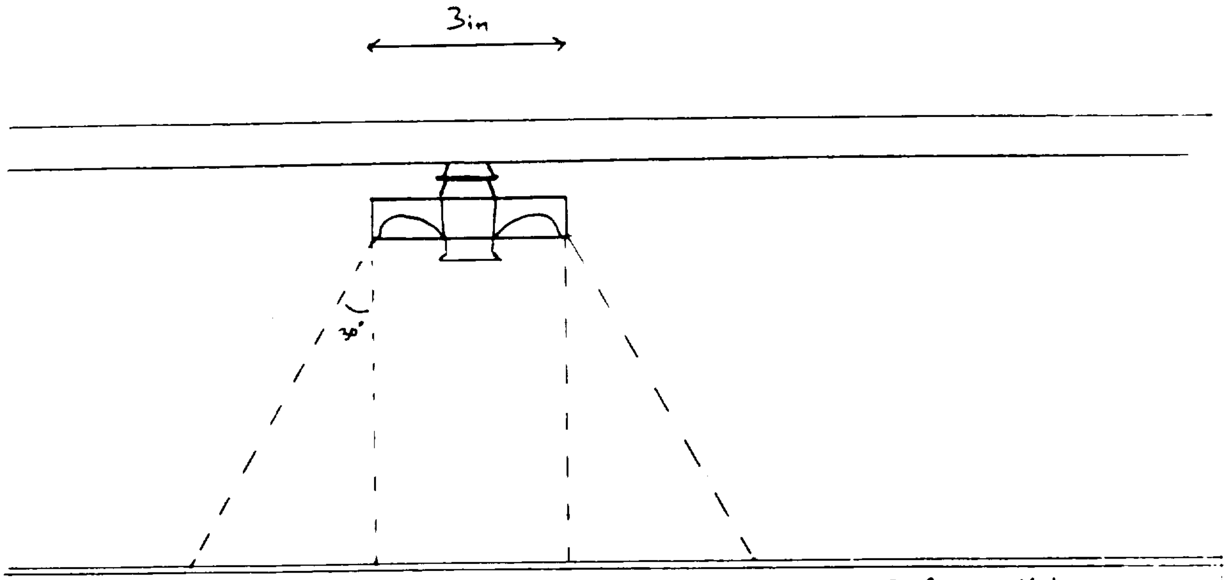
Table 4.10. Heat losses from bare steel surfaces* (See Example 4-10)

Surface temperature, F	Surface temperature, C	Horizontal flat facing down, 0 fps		Horizontal flat facing up, 0 fps		Horizontal cylinder, 0 fps		Vertical flat or cylinder, 0 fps		Vertical flat or cylinder, 10 fps (3.05 m/s)	Radiation heat loss only	
		Total heat loss, radiation and convection (heat loss in Btu/ft² hr and kcal/m² s)										
100	50	25	0.026	25	0.038	25	0.030	25	0.034	112	21.6	0.036
150		110		150		125		117		565	86.8	
200	100	225	0.188	290	0.256	240	0.203	265	0.226		170	0.146
250		365		470		405		430		845	275	
300	150	540	0.407	675	0.512	555	0.418	615	0.467	1135	404	0.309
350	200	745	0.704	905	0.866	760	0.711	840	0.791	1455	561	0.541
400		960		1180		1000		1090		1805	751	
450	250	1245	1.09	1500	1.12	1295	1.11	1395	1.24	2200	976	0.860
500		1575		1880		1625		1750			1242	
550		1950		2300		2000		2150			1554	
600	300	2450	1.60	2750	1.87	2400	1.64	2570	1.76		1913	1.29
650	350	2810	2.22	3200	2.57	2700	2.26	3050	2.41		2329	1.84
700		3340		3840		3410		3620			2800	
750	400	3950	2.79	4490	3.18	4025	2.86	4250	3.01		3346	2.54
800	450	4620	3.95	5205	4.37	4695	4.02	4950	4.22		3958	3.42
850		5370		6000		5400		5735			4645	
900	500	6200	4.91	6700	5.71	6300	5.18	6600	5.49		5424	4.49
950		7100		7875		7200		7540			6287	
1000	550	8110	6.40	9000	7.27	8210	6.49	8600	6.86		7250	5.81

* Largely from Reference 4.1 listed at the end of Part 4. Based on 80 F ambient air and steel surface emissivity of 0.95. For heat loss from non-steel surfaces, a) find convection only, = total − radiation; b) find non-steel radiation = steel radiation × emissivity of non-steel surface ÷ 0.95; c) add convection from (a) and non-steel radiation from (b) = total heat loss from the non-steel surface.

49

Scale: .6 in/sq



Angle: 30° off of refractory on cup

$\tan 30° = \frac{x}{8.33}$ $\quad x = 4.81$ sq $\quad \tan 30° = \frac{x}{5''}$

$x = 2.89$ in

Area covered by each burner

$D = 2x + 5$ sq $= 14.62$ sq $\left(.6 \text{ in}/\text{sq} \right) = 8.77$ in

$R = 4.386$ in

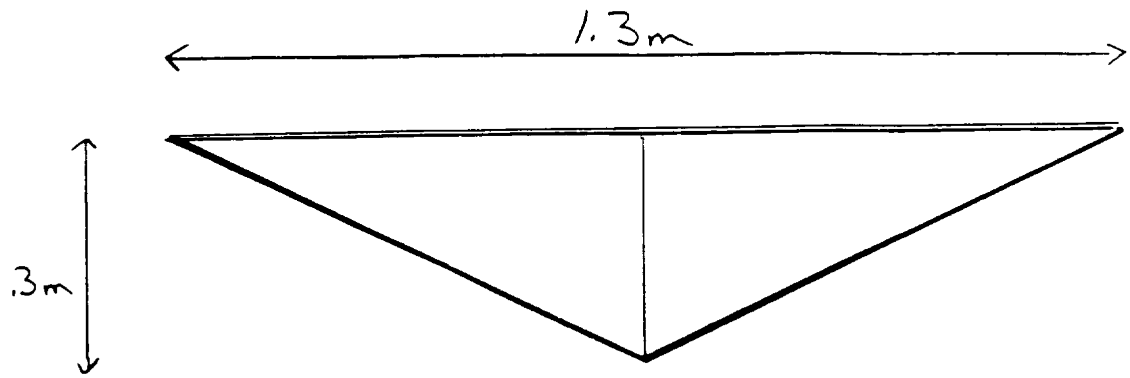
$A = \pi R^2 = 60 \text{ in}^2$

$60 \text{ in}^2 \left(\frac{ft}{12 \text{ in}} \right)^2 = .42 \text{ ft}^2$

$SA. = 14.95 \text{ ft}^2$

Need 35.6 Burners to cover entire surface

Design # 1 C



Surface area: $A_l = \pi r s = \pi r \sqrt{r^2 + h^2}$

$A_T = \pi r (r + s)$

$\pi r^2 + \pi r s$

$D = 1.3\,m$
$r = .65\,m$
$h = .3\,m$

$A_l = 1.462\,m^2$

Volume $= \dfrac{\pi r^2 h}{3} = .1327\,m^3$

Density of H_2O = 1000 kg/m^3

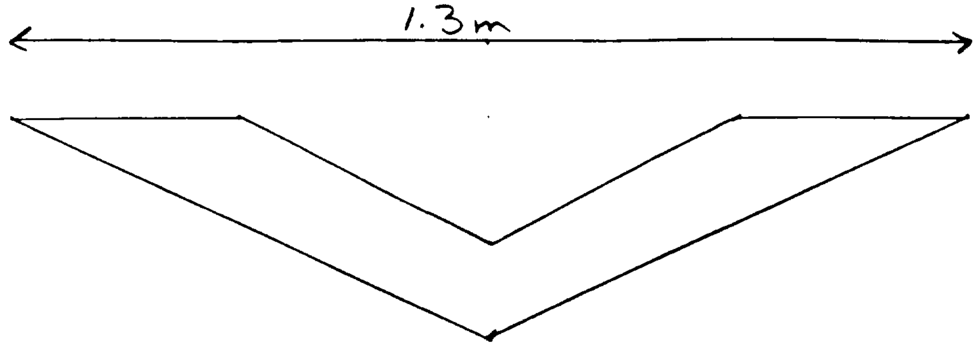
132.7 kg <u>weight</u>

≈ 292.55 lbs

1 kg = 2.2046 lbs

Not a good design !

Design #2 C



$.5 \text{ inch} \left(.26 \text{m}/_{\text{in}}\right) = .13 \text{m}$

$.13 \text{ m} \; \frac{100 \text{cm}}{1 \text{m}} \; \frac{1 \text{in}}{2.54 \text{cm}} = 5 \text{ inches}$

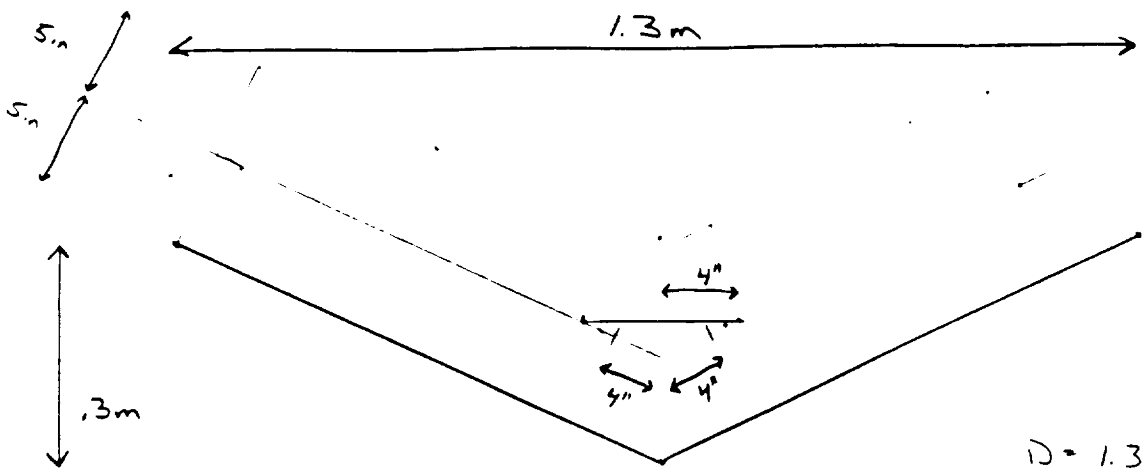
Need 10 inches

Need more space for burners

— burners radiant ~~to~~ spread heat how far

Design #3 C

scale .26 m/in



D = 1.3 m
r = .65 m
h = .3 m

$s = \sqrt{r^2 + h^2}$
$= .7159$ m ≈ 28.18 in 2' 4"

Distance from plate 5"

$5 \text{ in} \cdot \frac{2.54 \text{ cm}}{1}\left(\frac{m}{100 \text{ cm}}\right) = .127 \text{ m}$ $.127 \text{ m} \cdot \frac{\text{in}}{.26 \text{ m}} = .49$ in scale

8 in for distributor for propane + air mixture

r = 4" $C = 2\pi r$
$= 25.13$"

Can have six exiting tubes!

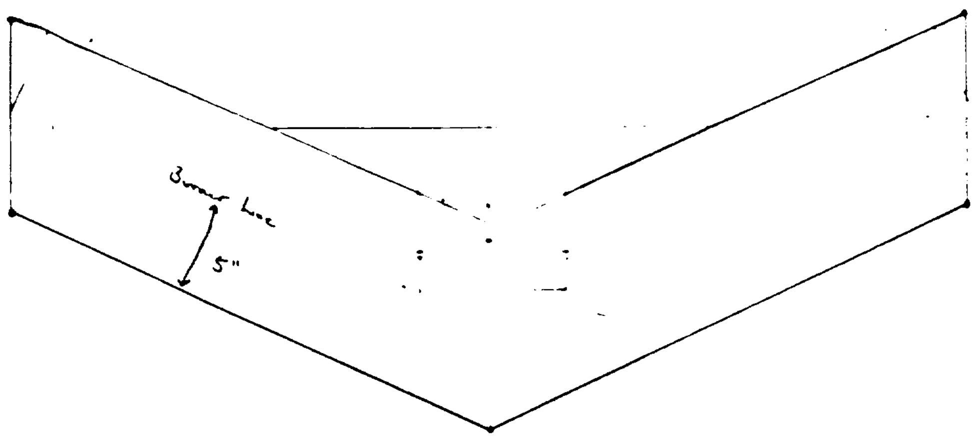
r = .65 m ≈ 25.6 in

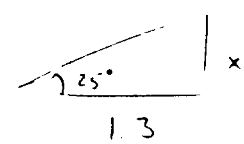
C = 160.8 in / 6 lines = every 26.8 inches

Not enough room for burners

Design 7 C

Scale .26 m/in

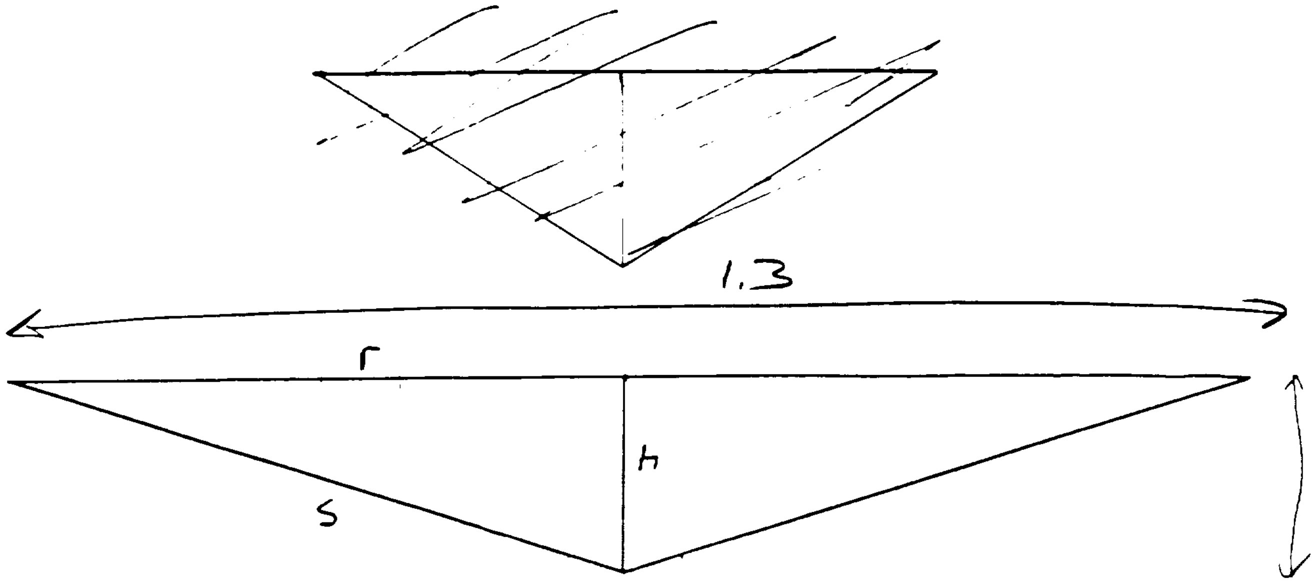




10" ≈ .254 m ≈ .977 scale

2.125 in scale $\left(.26\,m/in\right)$ = .5525 m = 21.75 in

Design # 5 C



$1.3\,m = 51'' = 4'3''$

$.2\,m = 7.87''$

$5\,in = .127\,m$

$r = .65\,m$

$h = .2\,m$

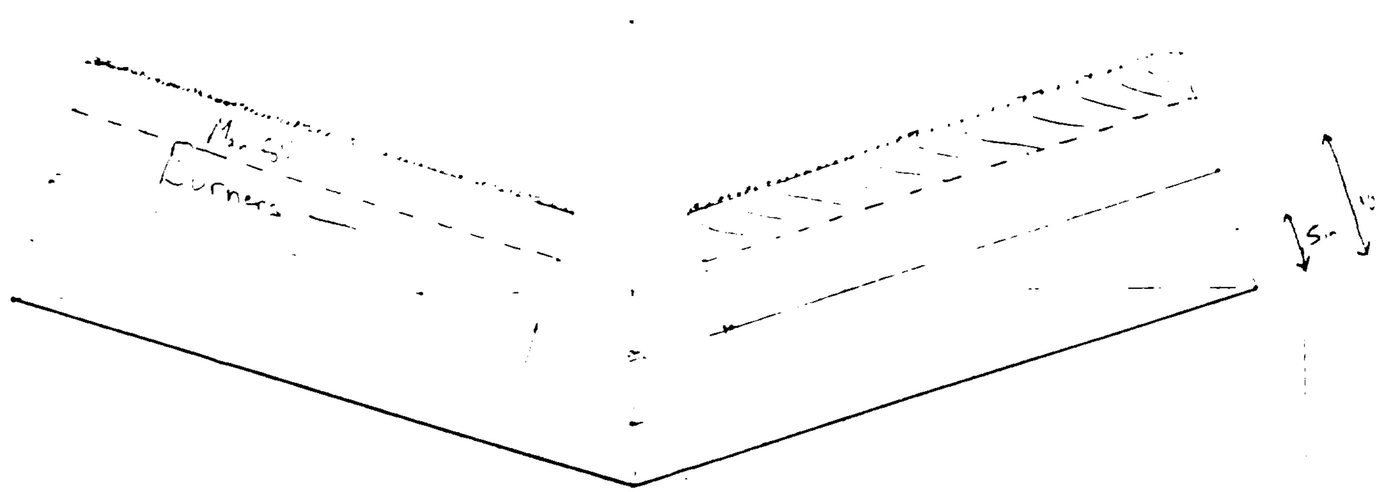
$s = \sqrt{r^2 + h^2}$
$= .4625$

Design #5 continued (8)

First set of Burners 4 inches away from distributor

Burner recieves $\underline{4.386\text{ in}}$ w/ radiant heat

4.386 in



10-LS goes all the way to end

10 inches needed – 5 in clearance = .127 m

5 in for burners = "

.254 m

Approx Volume = Original Vol – Cylinder – Top Cone

h = .25 m

r = .65 m

D(cone) = 1.15 m

r_c = .575 m

h(c) = .18 m

O Vol = 1.389

Vol C[illegible] =

Weight = 790 lb

Way to high

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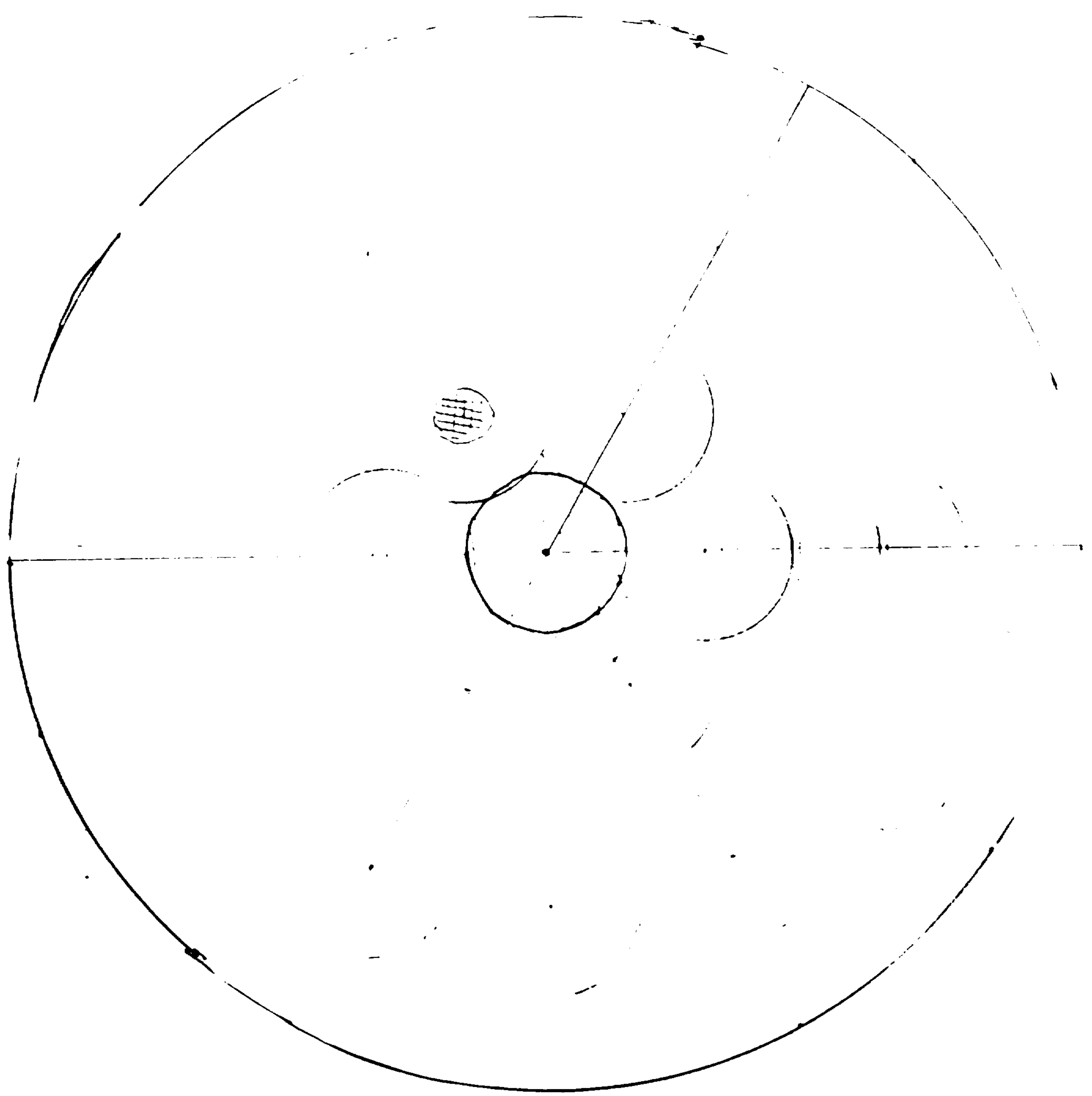
Design #5 (continued) C

Scale: 1m = 10cm

Above view

$s = .68\,m$
$2s = 1.36\,m$ new diameter



$r = .68m = 26.8$ in

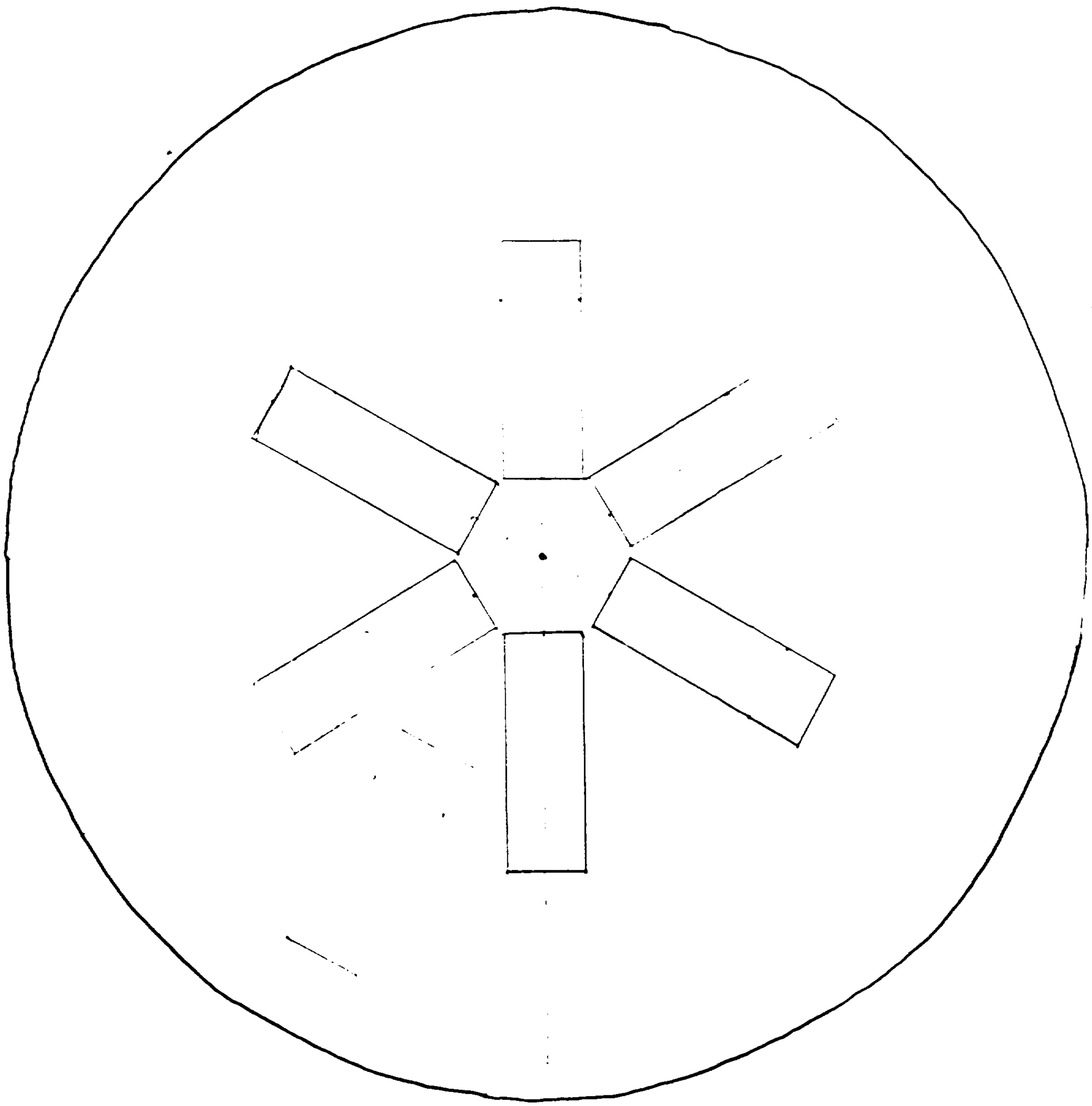
$C = 2\pi r = 168$ in $= 4.27m$

8 in centers

$r = 4.$ in distributer $= .102$ m
$C = 25.1$ in

$.256 m \approx$

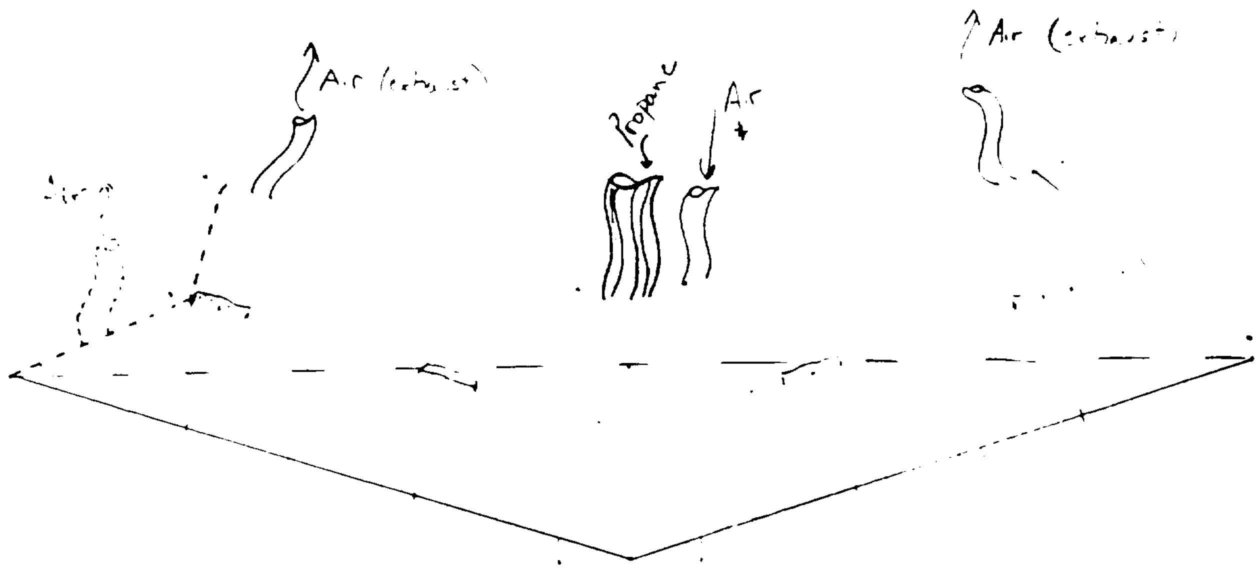
C



12" = .305 m
4" = .1016

Design / C

Cup Burners



18 burners

Volume =

cone $\frac{1}{3}\pi r^2 h$ = $\frac{1}{3}\pi .65^2 .2$ = .0885 .0885

cylinder $\pi r^2 h$ = r = .65 V = .10353

r_2 = .46 V = .05185 .10353

h = .078 .02584

.1294

V = .05168

= .02584

D = .92

Cylinder r = .46 h = .13 V_3 = .08642 $V_3 - V_4$ = .0554

Cone r = .46 h = .14 V_4 = .03102

Total Volume = .2733 m^3

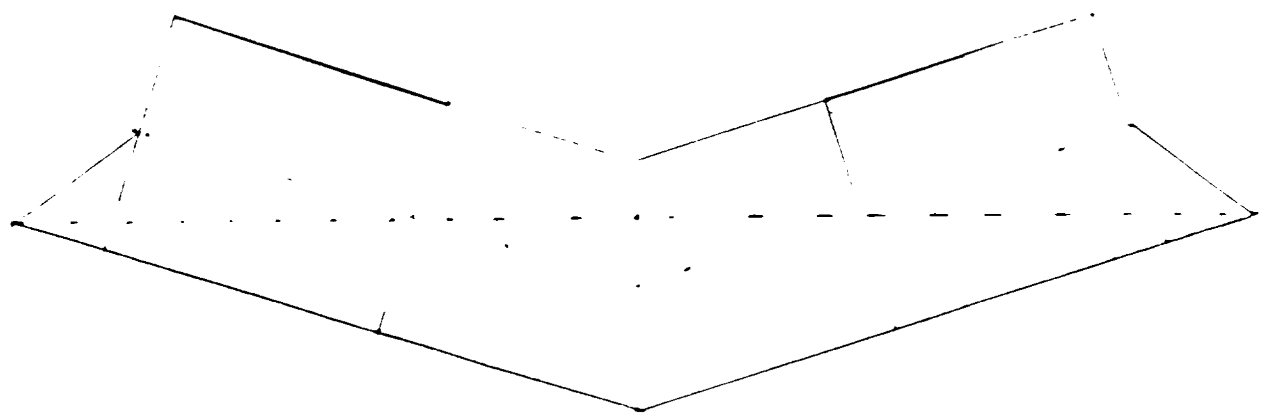
Density $\rho(H_2O)$ = ~1000~ kg/m³

273.3 kg

/kg = 2.2046 lb ≈ 602 lbs

Design # 8 C

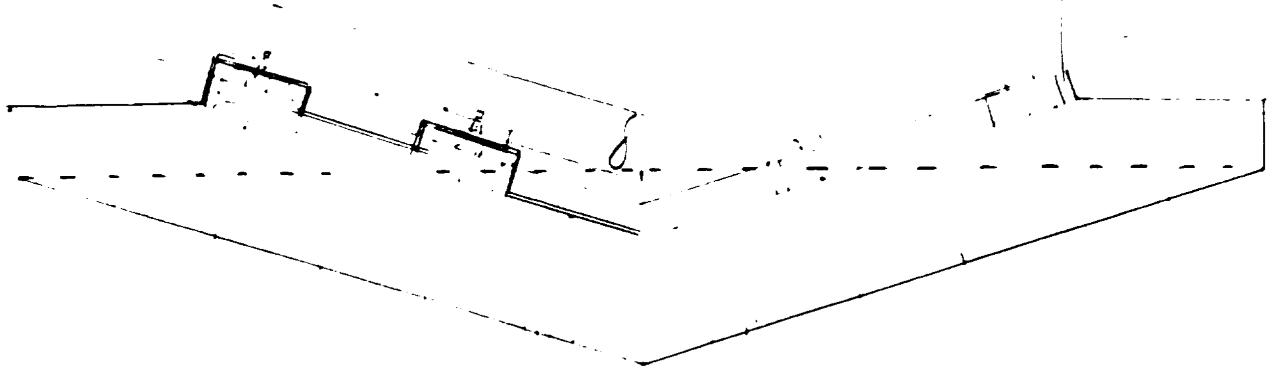
Line Burners ...



5" = .127m

This volume would need to weigh as much as last one
≈ 600 lbs (too heavy)

Design # 9 C



.2m = 7.87 in

6"

9"

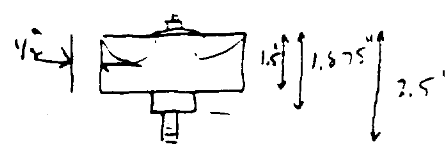
sin 17.1° = $\frac{.2}{.65}$

cos 17.1° = $\frac{x}{.1}$ x = .0956

3" = .0762 m

Diameter of burner = 3 in ≈ .0762 m
Diameter of surface vessel = 8.77 in ≈ .223 m

Burner height = 2.5" ≈ .0635
1.25 = .0318
1.875 = .0476



.5" = .0127m

Volume: Cone$_1$ = $\frac{1}{3}\pi r^2 h$ r = .65, h = .2 V_1 = .0885

Cylinder = $\pi r^2 h$ r = .65, r = .07 V_2 = .0929

- Cone$_2$ r = .455, h = ~~.07~~ .140 V_3 = .0304

Rectangles with Ends h = 5", 1.875" V_4 = .00157

sub Total Volume = Cone$_1$ + Cyl − Cone$_2$ = .151 .151

12 × V_4 = 12 × = .050 .0189

.201 m^3 .1699 m^3

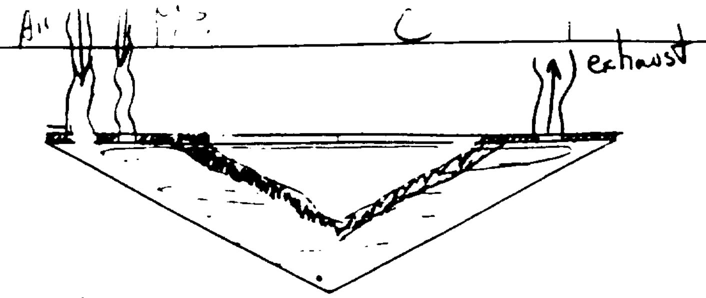
201 kg 170 kg

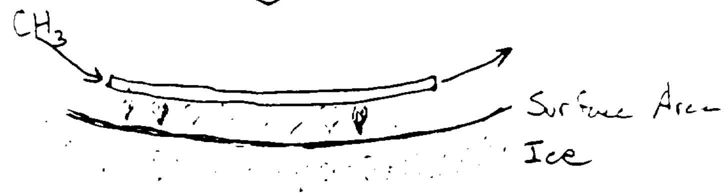
443 lbs 375 lbs

Cylinders $\pi r^2 h$
r = 2" ≈ .051
h = 1.875" ≈ .0476
V = .000389
12·V = .00467

Density of H_2O = 1000 kg/m^3
1 kg = 2.2046 lbs

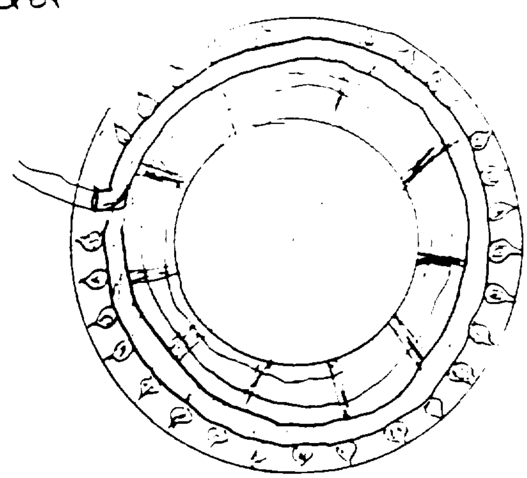
.151 + .00467 = .1557





Requirements:

1) pump for Air
2) pump or compressed Methane (CH_2) gas
3) enough methane gas
4) generator



Energy - Using Gas

C

Propane - Gas

Allied propane service 237-7077

how much per tank ?

Energy in each tank ?

100 lb bottle 24 gallons

91,500 BTU/gallon 2,196,000 BTU/bottl.

propane (liquid)

Need 7,211,000 BTU

Propane 91,500 BTU/gallon

$$\frac{7,211,000 \text{ BTU}}{91,500 \text{ BTU/gal}} = 78.8 \text{ gal}$$

24 gal bottle 100 lbs propane 80 lb canister

180 lbs total

96 gal / 720 lbs $\Longrightarrow$ 4 : 180 lb. bottles

C

Burners $\Longrightarrow$ Too much fuel required

Burner 25,000 BTU/hr   Methane 1000 BTU/ft^3

Energy needed $\rightarrow$ 7,211,000 BTU

Rate for 1 burner $\dfrac{25{,}000 \text{ BTU/hr}}{1000 \text{ BTU/ft}^3} = 25 \text{ ft}^3/\text{hr}$

Hrs of Energy $= \dfrac{7{,}211{,}000 \text{ BTU}}{25{,}000 \text{ BTU/hr}} = 288.44 \text{ hrs}$

Amount needed $\Rightarrow$ $288.44 \text{ hrs} \quad 25 \text{ ft}^3/\text{hr} = 7211 \text{ ft}^3$

100 lb bottle holds 25 gallons gass

$1 m^3 = 264.2 \text{ gal}$ $1 m^3 \dfrac{(100 cm)^3}{1 m^3} \times \left(\dfrac{1 in}{2.54 cm}\right)^3 \cdot \left(\dfrac{ft}{12 in}\right)$

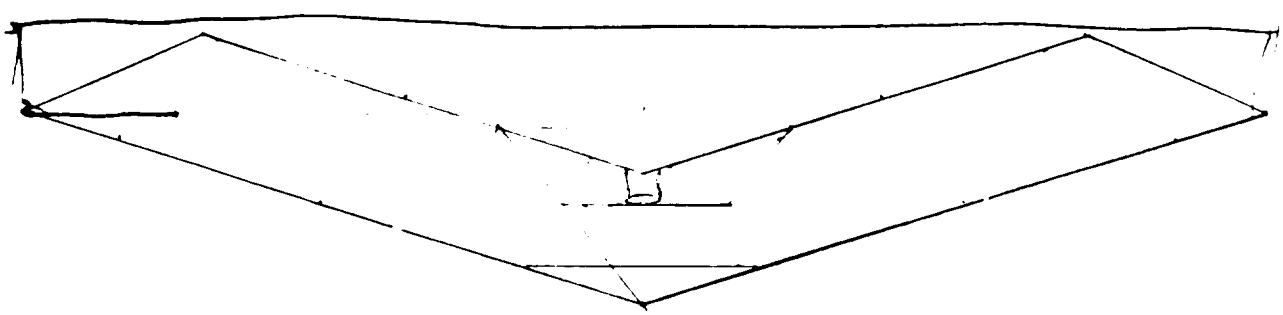
$1 m^3 = 35.315 \text{ ft}^3$

$7211 \text{ ft}^3 \quad \dfrac{1 m^3}{35.315 \text{ ft}^3} \times \dfrac{264.2 \text{ gal}}{1 m^3}$

53947 gal of Methane

2158 bottles (100 lb bottles)

Design # | 10 | C



$r = .15$ $h_0 = .05$

$h_1 = .18$

$\frac{1}{3}\pi r^2 h$

Volume = ~~Cone~~ $\cancel{\pi r\sqrt{r^2+h^2}} = \cancel{1.389}$ | $V_{cone} = \cancel{1.389}$ .0885

Cylinder 1 $\pi r^2 h$ $\cancel{2\pi r h}$ $r = .65$ $h = .07$ | $V_{cyl_2} = \cancel{.2859}$ .0929

Cylinder 2 $r = .455$ | $V_{cyl_2} = \cancel{.2001}$ .0455

$cone_2$ $r = .455$ $h = .145$ | $V_{cone_2} = \cancel{.6826}$ .0314

$Cone_3$ $r = .15$ $h = .18$ | $V_{cone_3} = \cancel{.1104}$ .00424

Cone 4 $r = .15$ $h = .045$ | $V_{cone_4} = \cancel{.0738}$ .00106

Cone 5 $r = .085$ $h = .1$ | $V_{cone_5} = \cancel{.0350}$ .00076

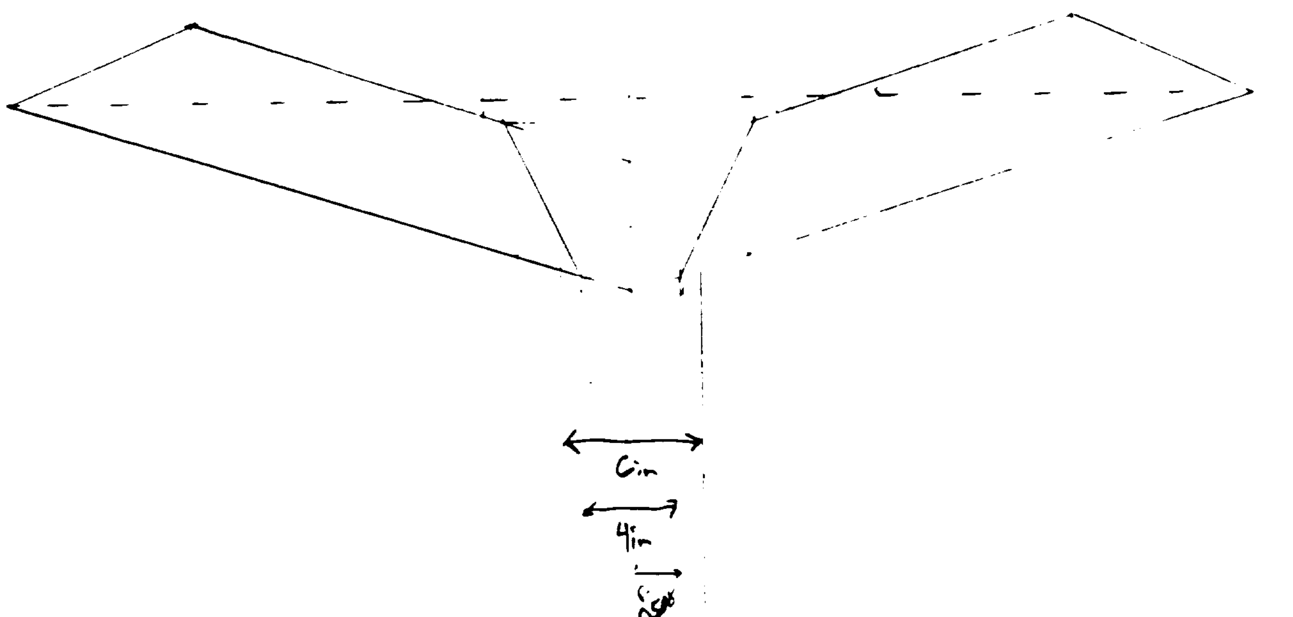
$$V_{cone} + V_{cyl_2} + \frac{V_{cyl_1} - V_{cyl_2}}{2} - V_{con_2} - V_{cone_3} + V_{con_4} + V_{cone_5} = V_T$$

$$\cancel{1.389} + \cancel{.2001} + .0429 - \cancel{.6826} - \cancel{.1104} + \cancel{.0738} + \cancel{.0350} = V_T$$

$$.0885 + .0455 + .0237 - .0314 - .00424 + .00106 + .00076$$

$$V_T = \cancel{.947}\ .124$$

Design # 11 C



$Cone_1 = \frac{1}{3}\pi r^2 h$	$V_{cone_1} = .0885$	$Cone_3$	$r = .13$	$h = \cancel{.175}$ .265	$V_3 = .00469$
	$V_{cyl_1} = .0455$	$Cone_4$	$r = .13$	$h = .04$	$V_4 = .00071$
	$V_{slant} = .0237$	$Cone_5$	$r = .0508$	$h = \cancel{.0875}$ .1	$V_5 = .00027$
	$V_{cone_2} = .0314$	$Cone_6$	$r = .0508$	$h = .0133$	$V_6 = .0000359$

$V_{cone_1} + V_{cyl} + V_{slant} - V_{cone_2} - V_{cone_3} + Cone_4 + Cone_5 - Cone_6$

$.0885 + .0455 + .0237 - .0314 - .00469 + .00071 + .00027 - .0000359$

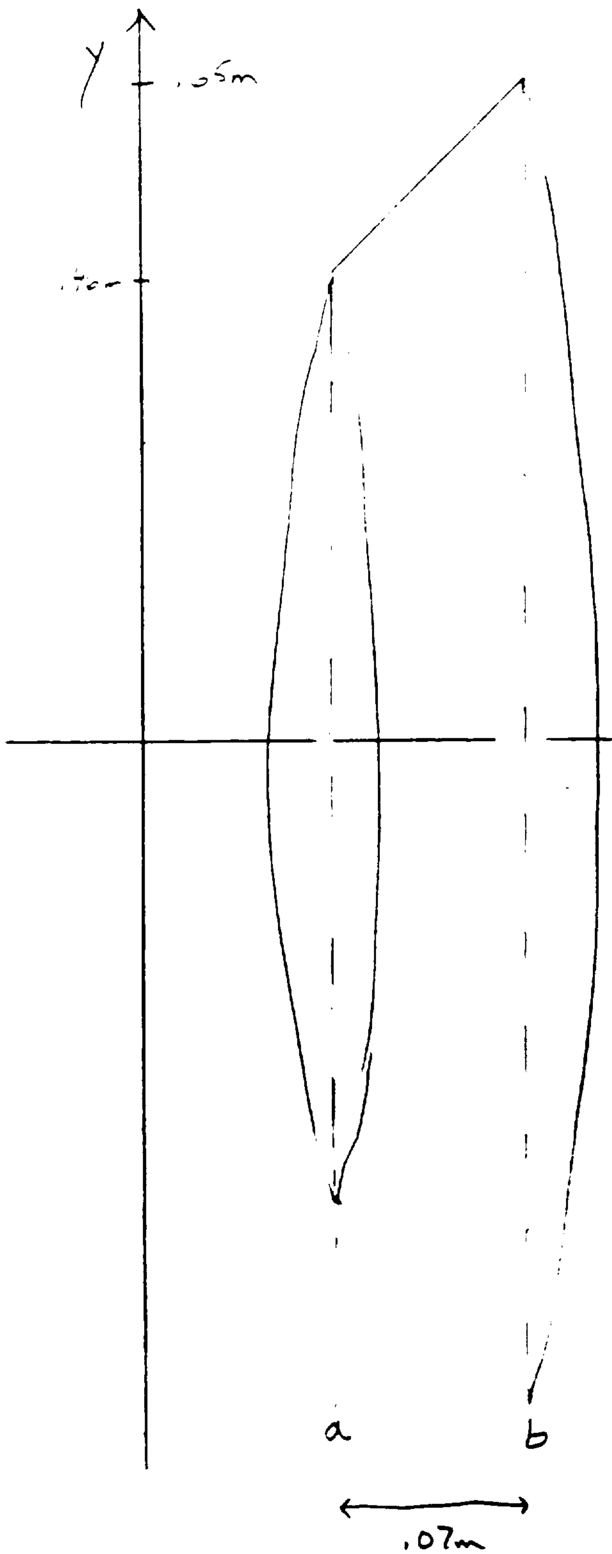
$V_T = .1226$

122.6 kg ≈ 270.2 lbs

Outside C
Surface Area

revolved around x-axis

$$S = \int_a^b 2\pi f(x) \sqrt{1 + (f'(x))^2}\, dx$$



$y = cx + d$

c = slope

d = y intercept

$$\text{slope} = \frac{.65 - .46}{.07} = \frac{.19}{.07} = 2.7143$$

$y = 2.7143x + d$

Assume $d = 0$

$$S = \int_0^{.07} 2\pi (2.7143x)\sqrt{1 + 7.3674}\, dx$$

$$2\pi(2.7143x)\, 2.89265$$

$$\int_0^{.07} 49.3326x$$

$$24.6663x^2 \Big|_0^{.07}$$

$$= .12086$$

Volume C

Manifolds $\cancel{\#}$ (.0254 m + .42 + .48) × 12
+ .2425 × 6 = 4.051 m
159.5" / 13' 3½"

Density (steel) 7978 kg/m³

Gas distributer

Diameter 1.57" R = .785"
H = .5"

$2\pi rh$ = 2.466 in² (1/8") thick
V = .3083 in³

Air Distributer
Diameter 2.00" r = 1"
h = .5"

$2\pi rh$ = 3.142 in² (1/8") thick
V = .3927 in³

$.3083 \text{ in}^3 \left(\frac{1 \text{ ft}}{12 \text{ in}}\right)^3 \times \frac{7978 \text{ kg/m}^3}{\cancel{\text{lb/ft}}} \quad \frac{1 \text{ lb/ft}^3}{16.018 \text{ kg/m}^3}$

.0888 lbs

.3927 in³
.1132

Appendix D

System Specifications

1.3 m diameter hole (R = 0.65 m)
4.2 m deep
1600 lb max. (727 kg)
Max. melting time: 24 hrs
Lifetime of 10 holes (3 years)
Operating Temperature range: 50°C to 20°C

Energy Balance

$$q_{in} = q_{flow} + q_{heat} + q_{melt}$$

$q_{flow} = \rho_{water} V_{flow} A_{exit} C_p (T_{out} - T_c)$ where

$\rho_{water} = 1000\ kg/m^3$ (Assumed constant)

V_{flow} = Velocity of the flow of melted water $\left[\frac{m}{s}\right]$

$A_{exit} = 2\pi R \Delta x\ \left[m^2\right]$

$C_{p,water}$ = Heat capacity of water at $T_{out} \left[\frac{J}{kgK}\right]$

T_{out} = Outlet temperature [K]
T_c = 273 K (Melting point of water)

q_{flow} is the energy lost as the water flows out from beneath the melter.

$q_{heat} = \rho_{ice} A \frac{dx}{dt} C_p (T_c - T_{ice,ave})$ where

$\rho_{ice} = 920\ kg/m^3$

A = Area of melter $\left[m^2\right]$

$\frac{dx}{dt}$ = Downward velocity of the melter [m/s]

$C_{p,ice}$ = Average heat capacity of the ice $\left[\frac{J}{kgK}\right]$

T_c = 273 K (Melting point of water)

$T_{ice,ave} = 248\ K \left((T_{ice,ave}) = \frac{273 + 223}{2} \right)$

q_{heat} is the energy required to raise the temperature of the ice to 273 K

$q_{melt} = \rho_{ice} A \frac{dx}{dt} H_f$ where

$\rho_{ice} = 920\ kg/m^3$

A = Area of melter $\left[m^2\right]$

$\frac{dx}{dt}$ = Downward velocity of the melter [m/s]

H_f = Latent heat of fusion for water $\left[\frac{J}{kg}\right]$

q_{melt} is the energy required to melt the ice at 273 K

D

Also, from convection,

$$q_{flow} = h_h A(T_h - T_m) - h_c A(T_m - T_c) \text{ and}$$

$$q_{melt} + q_{heat} = h_c A(T_m - T_c)$$

$$\text{where } T_m = \left(\frac{T_h + T_c}{2}\right)$$

This two-step process was required since the properties of water change drastically between 273 K and 373 K.

Heat Convection Coefficients

The convection ceofficient h is a function of temperature and flow velocity. The equation for $\bar{h}_T$, that is, h_{ave} determined at the temperature T, is:

$$\bar{h}_T = \frac{k(T)}{\Delta x}\left[0.66\, R_e^{1/2}\, P_r(T)^{1/3}\right] \text{ where}$$

$$R_e = \frac{V_{flow}R}{\nu(T)} = \frac{\text{(Flow Velocity)(Melter Radius)}}{\text{Kinematic Voscocity}} \quad \text{[Reynold's Number]}$$

$P_r(T)$ = Prandtl Number (Physical Characteristic)

Solution by Iteration

To solve this system of equations, I created an Excel spreadsheet to solve the equations iteratively given an initial guess for some values. The solutions converged to a particular solution in all cases.

The equations used are:

1) q_{flow}: $$\rho_{ice} A \frac{dx}{dt} C_p (T_{flow} - T_c) = h_h A(T_h - T_{flow}) - h_c A(T_{flow} - T_c)$$

2) $q_{melt} + q_{heat}$: $$\rho_{ice} H_f A \frac{dx}{dt} + \rho_{ice} A \frac{dx}{dt} C_p\,(25\text{ K}) = h_c A(T_{flow} - T_c)$$

3) h: $$h_{h,c} = \frac{k(T_{f\,h,c})}{R}\, 0.664 \left[\frac{\frac{R^2}{\Delta x}\frac{dx}{dt}}{\nu(T_{f\,h,c})}\right]^{1/2} (P_r(T_{f\,h,c}))^{1/3}$$

The unknowns are: T_{flow} and $\frac{dx}{dt}$

The convection coefficients are dependent on T_{flow} and $\frac{dx}{dt}$.

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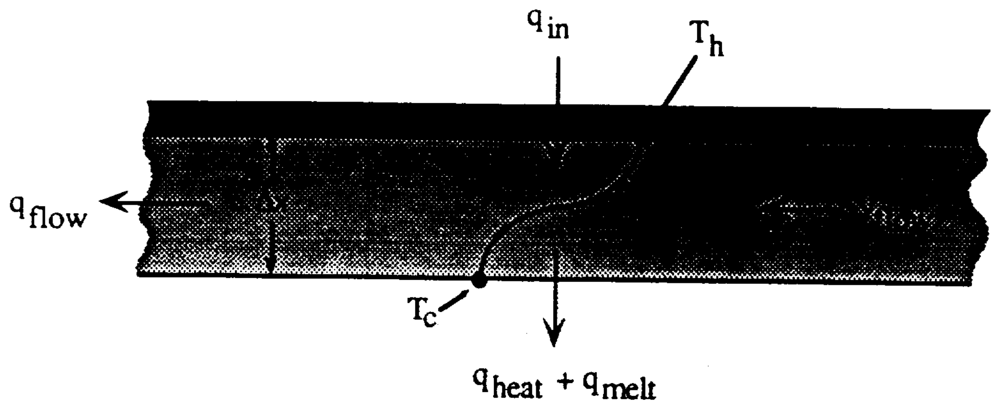
Also, many of the material properties of water are temperature dependent

The iterations were as follows:

1. Assume values for T_{flow} and $\frac{dx}{dt}$.
2. Determine water properties at the appropriate film temperatures.

$$T_{f\,h} = \frac{T_h + T_{flow}}{2} \qquad T_{f\,c} = \frac{T_{flow} + T_c}{2}$$



Heat Transfer

in the
Antarctic Ice Melter

Rad=	0.65	Radius of hole (m)
height=	0.2	Height of Cylindrical Pyramid (m)
Area=	1.389	Area of hole (m^2)
rho=	920	Density of ice (kg/m^3)
Tc=	273	Temperature of Ice (K)
Hf=	333458	Heat of Fusion (J/Kg)
depth=	4.2	Depth of hole (m)

Shell Temp.	Exit Temp	Downward Velocity	Convection Coefficients				Heat Flows				Efficiency	Time
			Hot		Cold		Fluid	Ice	Melting	Total		
Th	Tinf1	dx/dt 1	Tfh	hh	Tfc	hc	qflow	qheat	qmelt	qin	%	(Hours)
280	276.47	0.000005	278.2	476.98	274.7	464.88	98	630	2239	2967	75.5%	221.95
Th	Tinf1	dx/dt 1	Tfh	hh	Tfc	hc	qflow	qheat	qmelt	qin	%	Hours
300	286.09	0.000021	293.0	527.63	279.5	481.51	1441	2460	8750	12650	69.2%	56.81
Th	Tinf1	dx/dt 1	Tfh	hh	Tfc	hc	qflow	qheat	qmelt	qin	%	Hours
325	297.57	0.000040	311.3	587.34	285.3	501.25	5272	4807	17097	27176	62.9%	29.07
Th	Tinf1	dx/dt 1	Tfh	hh	Tfc	hc	qflow	qheat	qmelt	qin	%	Hours
350	308.50	0.000060	329.3	642.82	290.8	519.88	11413	7204	25624	44241	57.9%	19.40
Th	Tinf1	dx/dt 1	Tfh	hh	Tfc	hc	qflow	qheat	qmelt	qin	%	Hours
373	318.18	0.000079	345.6	692.33	295.6	536.17	19070	9455	33629	62154	54.1%	14.78
Th	Tinf1	dx/dt 1	Tfh	hh	Tfc	hc	qflow	qheat	qmelt	qin	%	Hours
400	329.26	0.000102	364.6	752.73	301.1	554.55	30620	12177	43313	86111	50.3%	11.48
Th	Tinf1	dx/dt 1	Tfh	hh	Tfc	hc	qflow	qheat	qmelt	qin	%	Hours
425	338.86	0.000122	381.9	796.86	305.9	570.18	43187	14655	52127	109970	47.4%	9.54
Th	Tinf1	dx/dt 1	Tfh	hh	Tfc	hc	qflow	qheat	qmelt	qin	%	Hours
450	345.92	0.000138	398.0	781.97	309.5	581.54	54099	16557	58890	129545	45.5%	8.44
Th	Tinf1	dx/dt 1	Tfh	hh	Tfc	hc	qflow	qheat	qmelt	qin	%	Hours
475	350.27	0.000148	412.6	716.04	311.6	588.46	61165	17703	62968	141836	44.4%	7.89

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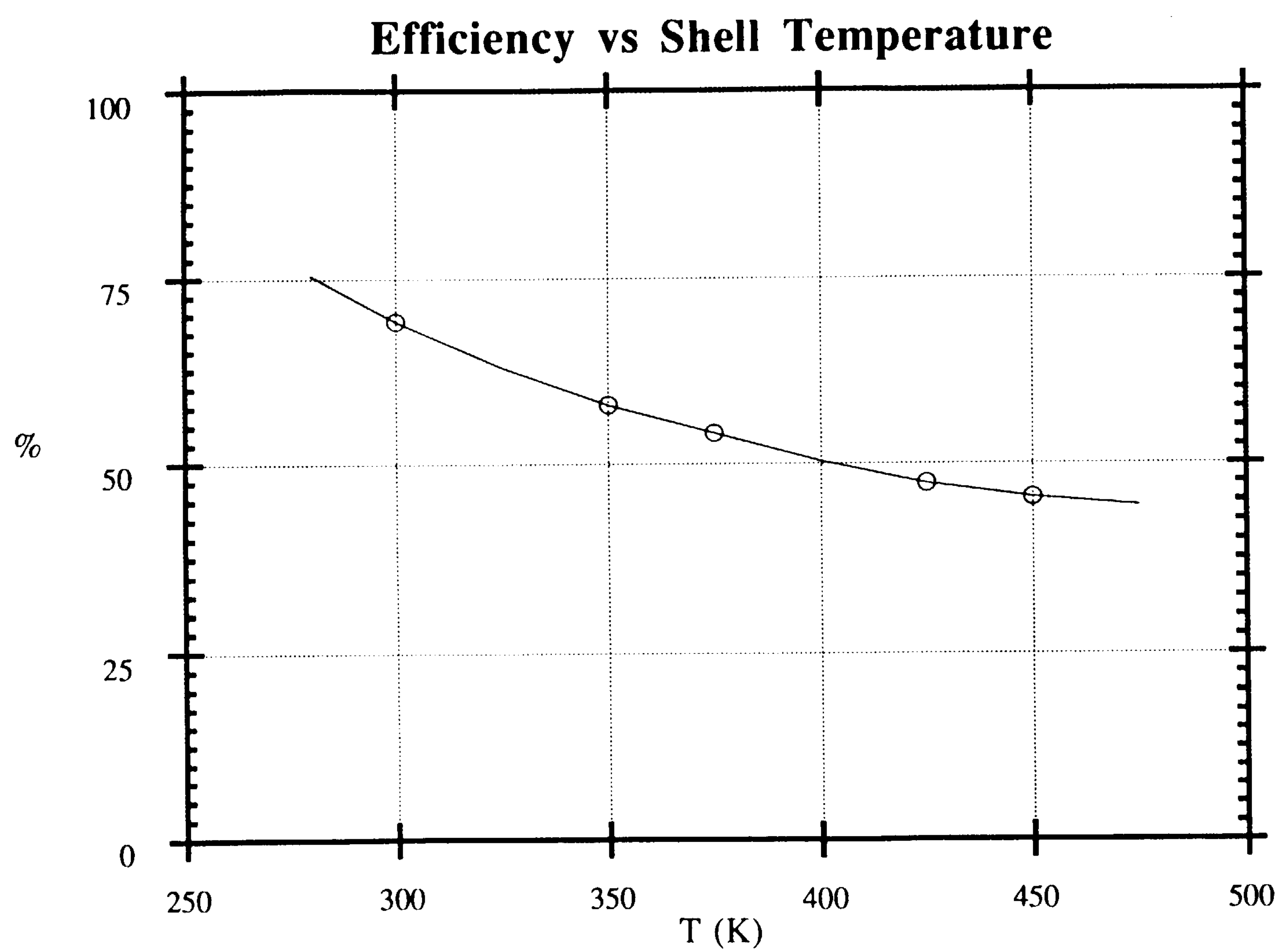
Efficiency vs Shell Temperature
%
100
75
50
25
0
250
300
350
400
450
500
T (K)